SBIR/STTR 2001-1

National Aeronautics and Space Administration

SMALL BUSINESS INNOVATION RESEARCH (SBIR) & TECHNOLOGY TRANSFER (STTR)

Program Solicitations

Opening Date: March 28, 2001
Closing Date: June 6, 2001

***An electronic version of this document is located at:* http://sbir.nasa.gov**

Cover: The TransHab inflatable living quarters is shown under test at NASA's Johnson Space Center for potential utilization by the International Space Station, as shown in the inset. ***Cover layout:*** *Dr. James Kalshoven, Jay Friedlander and Vivek Dwivedi of the NASA Goddard Space Flight Center.*

TABLE OF CONTENTS

2001 NASA SBIR/STTR Program Solicitations

1. Program Description

1.1 Introduction

This document includes two NASA program solicitations with separate research areas under which small business concerns (SBCs) are invited to submit proposals: the Small Business Innovation Research (SBIR) program and the Small Business Technology Transfer (STTR) program. In the past, NASA has issued separate SBIR and STTR solicitations. Because of the similarities in the execution of these programs, this single document is being issued for FY 2001.

The STTR Program is modeled on the SBIR program with the additional purpose to encourage the transfer of the intellectual concepts and ideas resident in our nation's non-profit Research Institutes (RIs). The STTR program allows the principal investigator (PI) to be employed at the RI, while the SBIR program requires that the PI have primary employment at the SBC. In addition, STTR proposals *must* include a formal cooperative research agreement between the SBC and the RI. SBIR proposals *may* involve collaboration between the SBC and other organizations, including a RI. For the STTR program, not less than 40 percent of the work (amount requested including cost sharing, less fee, if any) is to be performed by the SBC as the prime contractor, and not less than 30 percent of the work is to be performed by the RI. For the SBIR Program, not less than 2/3 of the work is to be performed by the SBC as the prime contractor during Phase I, and not less than 50 percent of the work is to be performed by the SBC as the prime contractor during Phase II.

This document contains program background information, outlines eligibility requirements for participants, describes the three program phases, and provides information for submitting responsive proposals. The 2001 Solicitation period for Phase I proposals begins March 28, 2001 and ends June 6, 2001.

The purposes of the SBIR/STTR programs, as established by law, are to stimulate technological innovation in the private sector; to strengthen the role of SBCs in meeting federal research and development needs; to increase the commercial application of these research results; and to encourage participation of socially and economically disadvantaged persons and women-owned small businesses.

To be eligible for selection, a proposal must be based on an innovation having high technical or scientific merit that is responsive to a NASA need described herein, and which offers potential commercial application. Proposals must be submitted via the internet (http://sbir.nasa.gov) and include all relevant documentation. Unsolicited proposals will not be accepted.

A proposal directed towards system studies, market research, routine engineering development of existing products or proven concepts and modifications of existing products without innovative changes is considered non-responsive. Selection preference will be given to eligible proposals where the innovations are judged to have significant potential for commercial application.

Subject to the availability of funds, NASA plans to select around 300 SBIR and 20 STTR Phase I proposals for negotiation of fixed-price contracts in September 2001. Historically, the ratio of the number of Phase I proposals to awards for SBIR is 7:1 and for STTR is 5:1.

1.2 Program Authority

SBIR: This Solicitation is issued pursuant to the authority contained in P.L. 106-554. Government-wide SBIR policy is provided by the Small Business Administration (SBA) through its Policy Directive. The current law authorizes the program through September 30, 2008.

STTR: This Solicitation is issued pursuant to the authority contained in P.L. 102-564. Government-wide STTR policy is provided by the SBA through its Policy Directive. The current law authorizes the program through September 30, 2001.

1.3 Program Management

The Office of Aerospace Technology provides overall policy direction for the NASA SBIR/STTR programs. The Program Management Office is hosted at the Goddard Space Flight Center. The Procurement Management Office is hosted at Glenn Research Center.

The SBIR Program Solicitation is aligned with NASA's five Strategic Enterprises (http://www.nasa.gov). The needs of all Strategic Enterprises are reflected in the research areas identified in Section 8.

The STTR Program Solicitation is aligned with the NASA Centers of Excellence. Each Center of Excellence participates every other year. JPL does not participate in the management of the STTR program.

Information regarding the Strategic Enterprises and the NASA Centers can be obtained at the following websites:

NASA Strategic Enterprises	
Aerospace Technology	http://www.hq.nasa.gov/office/aero
Biological and Physical Research	http://SpaceResearch.nasa.gov
Earth Science	http://earth.nasa.gov
Human Exploration and Development of Space	http://www.hq.nasa.gov/osf/heds/
Space Science	http://spacescience.nasa.gov/

NASA Installations	
Ames Research Center (ARC)	http://www.arc.nasa.gov
Dryden Flight Research Center (DFRC)	http://www.dfrc.nasa.gov
Glenn Research Center (GRC)	http://www.grc.nasa.gov
Goddard Space Flight Center (GSFC)	http://www.gsfc.nasa.gov
Jet Propulsion Laboratory (JPL)	http://www.jpl.nasa.gov
Johnson Space Center (JSC)	http://www.jsc.nasa.gov
Kennedy Space Center (KSC)	http://www.ksc.nasa.gov
Langley Research Center (LaRC)	http://www.larc.nasa.gov
Marshall Space Flight Center (MSFC)	http://www.msfc.nasa.gov
Stennis Space Center (SSC)	http://www.ssc.nasa.gov

1.4 Three-Phase Program

1.4.1 Phase I. The purpose of Phase I is to determine the scientific, technical, and commercial merit and feasibility of the proposed innovation, and the quality of the SBC's performance with a relatively small NASA investment before consideration of further Federal support in Phase II. Successful completion of Phase I objectives is a prerequisite to Phase II consideration.

Phase I must concentrate on establishing the scientific or technical merit and feasibility of the proposed innovation and on providing a basis for continued development in Phase II. Proposals must conform to the format described in Section 3.2. Evaluation and selection criteria are described in Section 4.1. NASA is solely responsible for determining the relative merit of proposals, their selection for award, and judging the value of Phase I results.

Maximum funding and period of performance for Phase I:

	SBIR	**STTR**
Maximum Contract Value	$ 70,000	$ 100,000
Duration	6 months	12 months

1.4.2 Phase II. The objective of Phase II is to continue the Research or Research and Development (R/R&D) effort from Phase I. Only SBCs awarded Phase I contracts are eligible for Phase II funding agreements, and only at the Federal Agency, which awarded the Phase I project. The Government is not obligated to fund any specific Phase II proposal. Contractors have up to 24 months to complete the effort and submit their final report.

Phase II projects are chosen as a result of competitive evaluations based on selection criteria provided in Section 4.2. Phase II proposals are more comprehensive than those required for Phase I and are to be prepared in accordance with instructions provided in the Phase I contract.

Maximum funding and period of performance for Phase II:

	SBIR	STTR
Maximum Contract Value	$ 600,000	$ 500,000
Duration	24 months	24 months

1.4.3 Phase III. NASA may award Phase III contracts for products or services with non-SBIR/STTR funds. Phase I and Phase II awards satisfy the requirements of the Competition in Contracting Act for subsequent NASA Phase III contracting. The small business is also expected to use non-Federal capital to pursue private sector applications of the R/R&D effort.

1.5 Eligibility Requirements

1.5.1 Small Business Concern. Only firms qualifying as SBCs, as defined in Section 2.1, are eligible to participate in these programs. Socially and economically disadvantaged and women-owned SBCs are particularly encouraged to propose.

STTR: To be eligible, SBCs must submit a cooperative research agreement with a RI.

1.5.2 Place of Performance. For both Phase I and Phase II, the R/R&D must be performed in the United States (Section 2.9).

1.5.3 Principal Investigator The primary employment of the PI must be with the SBC under the SBIR Program, while under the STTR Program the PI may be employed with the RI.

REQUIREMENTS	SBIR	STTR
Primary Employment	PI must be with the SBC	PI may be employed with the RI or SBC
Employment Certification	The offeror must certify in the proposal that the primary employment of the PI will be with the SBC at the time of award and during the conduct of the project. Primary employment means that the PI will average a minimum of 20 hours per week with the SBC, and that more than half of the PI's total employed time (including all concurrent employers, consulting, and self-employed time) is spent with the SBC. Primary employment with a small business concern precludes full-time employment at another organization. If the PI does not meet these primary employment requirements, the offeror must explain how these requirements will be met if the proposal is selected for contract negotiations that may lead to an award.	If the PI is not an employee of the SBC, the offeror must describe the management process to ensure SBC control of the project.

REQUIREMENTS	SBIR	STTR
Co-Principal Investigators	Not Acceptable	Not Acceptable
Misrepresentation of Qualifications	Will result in rejection of the proposal or termination of the contract	Will result in rejection of the proposal or termination of the contract
Substitution of PIs	Must receive advanced written approval from NASA	Must receive advanced written approval from NASA

1.6 General Information

1.6.1 Solicitation Distribution. This 2001 SBIR/STTR Program Solicitation is available via the NASA SBIR/STTR homepage **(http://sbir.nasa.gov)**. SBCs are encouraged to check the SBIR/STTR homepage for program updates. Any updates or corrections to the Solicitation will be posted there. If the SBC has difficulty accessing the Solicitation, contact the Help Desk (Section 1.6.2).

1.6.2 Means of Contacting NASA SBIR/STTR Program

(1) NASA SBIR/STTR Homepage: **http://sbir.nasa.gov**

(2) Each of the NASA field installations has its own homepage including strategic planning and program information. Please consult these homepages as noted in Section 1.3 for more details on the technology requirements within the subtopic areas.

(3) Help Desk. For inquiries, requests, and help-related questions, contact via:

e-mail: sbir@reisys.com
telephone: 301-937-0888 between 8:00 a.m. - 5:00 p.m. (Mon.-Fri., Eastern Time)
facsimile: 301-937-0204

The requestor must provide the name and telephone number of the person to contact, the organization name and address, and the specific questions or requests.

(4) NASA SBIR/STTR Program Manager. Specific information requests that could not be answered by the Help Desk should be mailed to:

Paul Mexcur, Program Manager
NASA SBIR/STTR Program Management Office
Code 712, Building 3, Room 108
Goddard Space Flight Center
Greenbelt, MD 20771-0001

1.6.3 Questions About This Solicitation. To ensure fairness, questions relating to the intent and/or content of research topics in this Solicitation cannot be answered during the Phase I solicitation period. Only questions requesting clarification of proposal instructions and administrative matters will be answered.

2. Definitions

2.1 Small Business Concern

An SBC is one that, at the time of award of Phase I and Phase II funding agreements, meets the following criteria:

(1) Is independently owned and operated, is not dominant in the field of operation in which it is proposing, has its principal place of business located in the United States, and is organized for profit;

(2) Is at least 51 percent owned, or in the case of a publicly-owned business, at least 51 percent of its voting stock is owned by United States citizens or lawfully admitted permanent resident aliens; and

(3) Has, including its affiliates, a number of employees not exceeding 500 and meets the other regulatory requirements found in 13 CFR Part 121. Business concerns, other than investment companies licensed, or state development companies qualifying under the Small Business Investment Act of 1958, 15 U.S.C. 661, et seq., are affiliates of one another when, either directly or indirectly, (1) one concern controls or has the power to control the other or (2) a third party controls or has the power to control both. Control can be exercised through common ownership, common management, and contractual relationships. The terms "affiliates" and "number of employees" are defined in greater detail in 13 CFR 121.

Small business concerns include sole proprietorships, partnerships, corporations, joint ventures, associations, or cooperatives. Eligible joint ventures are limited to no more than 49 percent participation by foreign business entities.

2.2 Research Institution

A U.S. research institution is one that is: (1) a contractor-operated federally funded research and development center, as identified by the National Science Foundation in accordance with the government-wide Federal Acquisition Regulation issued in section 35(c)(1) of the Office of Federal Procurement Policy Act (or any successor legislation thereto), or (2) a non-profit research institution as defined in section 4(5) of the Stevenson-Wydler Technology Innovation Act of 1980, or (3) a non-profit college or university.

2.3 Research or Research and Development (R/R&D)

Any activity that is (1) a systematic, intensive study directed toward greater knowledge or understanding of the subject studied, (2) a systematic study directed specifically toward applying new knowledge to meet a recognized need, or (3) a systematic application of knowledge toward the production of useful materials, devices, systems, or methods, including the design, development, and improvement of prototypes and new processes to meet specific requirements.

2.4 Cooperative Research or Research and Development

For purposes of the NASA STTR Program, cooperative R/R&D is that which is to be conducted jointly by the SBC and the RI in which at least 40 percent of the work (amount requested, including cost sharing if any, less fee if any) is performed by the SBC and at least 30 percent of the work is performed by the RI.

2.5 Subcontract

Any agreement, other than one involving an employer-employee relationship, entered into by a Federal Government contractor calling for supplies or services required solely for the performance of the original funding agreement.

2.6 Socially and Economically Disadvantaged Small Business Concern

A socially and economically disadvantaged SBC is one that is: (1) at least 51 percent owned by (i) an Indian tribe or a native Hawaiian organization or (ii) one or more socially and economically disadvantaged individuals; and (2) whose management and daily business operations are controlled by one or more socially and economically disadvantaged individuals.

2.7 Socially and Economically Disadvantaged Individual

A member of any of the following groups: Black Americans, Hispanic Americans, Native Americans, Asian-Pacific Americans, Subcontinent-Asian Americans, other groups designated from time to time by SBA to be socially disadvantaged, or any other individual found to be socially and economically disadvantaged by SBA pursuant to Section 8(a) of the Small Business Act, 15 U.S.C. 637(a).

2.8 Women-Owned Small Business

A women-owned SBC is one that is at least 51 percent owned by a woman or women who also control and operate it. "Control" in this context means exercising the power to make policy decisions. "Operate" in this context means being actively involved in the day-to-day management.

2.9 United States

Means the 50 states, the territories and possessions of the United States, the Commonwealth of Puerto Rico, the Trust Territory of the Pacific Islands, and the District of Columbia.

2.10 Commercialization

Commercialization is a process of developing markets and producing and delivering products or services for sale (whether by the originating party or by others). As used here, commercialization includes both Government and non-government markets.

3. Proposal Preparation Instructions and Requirements

3.1 Fundamental Considerations

Multiple Proposal Submissions. An offeror may submit **different** proposals in response to any number of subtopics, but every proposal must be based on an unique innovation, must be limited in scope to just one subtopic, and may be submitted only under that subtopic. *Submitting substantially equivalent proposals to several subtopics is not permitted and may result in all such proposals being rejected without evaluation.*

STTR: All Phase I proposals must provide sufficient information to convince NASA that the proposed SBC/RI cooperative effort represents a sound approach for converting technical information resident at the RI into a product or service that meets a need described in a Solicitation research subtopic. It must also identify the eventual commercial application potential of the product or service and discuss how the SBC would bring it to market.

End Deliverables. The deliverable item at the end of a Phase I contract shall be a comprehensive report that justifies, validates, and defends the experimental and theoretical work accomplished. Delivery of a product or service with the Phase I report may be desirable, but it is not a requirement.

Deliverable items for Phase II contracts shall include products or services in addition to professional quality reports of further developments or applications of the Phase I results. These deliverables may include prototypes, models, software, or complete products or services. The reported results of Phase II must address and provide the basis for validating the innovation and the potential for implementation of commercial applications.

Note: As part of the Phase I and Phase II deliverables, a non-proprietary technical abstract of findings shall be submitted by the offeror via the SBIR/STTR homepage.

3.2 Phase I Proposal Requirements

3.2.1 General Requirements

Page Limitation. A Phase I proposal shall not exceed a total of 25 standard 8 1/2 x 11 inch (21.6 x 27.9 cm) pages. A page is defined as a single side of a piece of paper. All four proposal items required in Section 3.2.2 will be included within this total. Each page shall be numbered consecutively at the bottom. Margins should be 1.0 inch (2.5 cm). **Proposals exceeding the 25 page limitation will be rejected during administrative screening.**

Web site references, product samples, videotapes, slides, or other ancillary items will not be accepted. Offerors are requested not to use the entire 25-page allowance unless necessary.

Type Size. No type size smaller than 10 point is to be used for text or tables, except as legends on reduced drawings. Proposals prepared with smaller font sizes will be rejected without consideration.

Classified Information. NASA does not accept proposals that contain classified information.

3.2.2 Format Requirements. All required items of information must be covered in the proposal. The space allocated to each part of the technical proposal will depend on the project chosen and the offeror's approach.

Each proposal submitted must contain the following four items in the order presented:

(1) Proposal Cover (Form 9A), signed, as page 1
(2) Proposal Summary (Form 9B), as page 2
(3) Technical Proposal (11 Parts in order as specified in Section 3.2.4), including all graphics, and starting at page 3 with a table of contents
(4) Summary Budget (Form 9C)

STTR: Each STTR proposal must also contain a Cooperative R/R&D Agreement between the SBC and RI following the four items listed above. This must be included as part of the 25-page limit.

3.2.3 Proposal Cover and Proposal Summary

Page 1: Proposal Cover (Form 9A). A sample copy of the Proposal Cover is provided in Section 9. The offeror shall provide complete information for each item and submit the form as required in Section 6. The proposal project title shall be concise and descriptive of the proposed effort. The title should not use acronyms or words like "Development of" or "Study of." The NASA research topic title must not be used as the proposal title.

Page 2: Proposal Summary (Form 9B). A sample copy of the Proposal Summary is provided in Section 9. The offeror shall provide complete information for each item and submit Form 9B as required in Section 6. The technical abstract portion is limited to 200 words and shall summarize the implications of the approach and the anticipated results of both Phase I and Phase II. Potential commercial applications of the technology should also be presented. If the technical abstract is judged to be non-responsive to the subtopic, the proposal will be rejected without further evaluation.

Note: Forms 9A and 9B, the Proposal Cover and the Proposal Summary, including the Technical Abstract, are public information and may be disclosed. Do not include proprietary information.

3.2.4 Technical Proposal. This part of the submission shall not contain any budget data and must consist of all eleven parts listed below in the given order. All parts must be numbered and titled; parts that are not applicable must be noted as “Not Applicable.”

Note: A proposal omitting any part will be considered non-responsive to this Solicitation and may be rejected during administrative screening.

Part 1: Table of Contents. Page 3 of the proposal shall begin with a brief table of contents indicating the page numbers of each of the parts of the proposal. A sample table of contents is included in Appendix A.

Part 2: Identification and Significance of the Innovation. The first paragraph of Part 2 shall contain:

(1) A clear and succinct statement of the specific innovation proposed, and why it is an innovation, and
(2) A brief explanation of how the innovation is relevant and important to meeting the technology need described in the subtopic. The initial paragraph shall contain no more than 200 words. NASA will reject

proposals that lack explanation of the innovation. In subsequent paragraphs, Part 2 may also include appropriate background and elaboration to explain the proposed innovation.

Part 3: Technical Objectives. State the specific objectives of the Phase I R/R&D effort including the technical questions that must be answered to determine the feasibility of the proposed innovation.

Part 4: Work Plan. Phase I R/R&D should address the objectives and questions cited in Part 3. The work plan should indicate what, where, and how it will be done. The methods planned to achieve each objective or task should be discussed in detail. Schedules, task descriptions and assignments, resource allocations, estimated task hours for each key personnel, and planned accomplishments including project milestones shall be included.

STTR: The work plan will specifically address the percentage and type of work to be performed by the SBC and the RI. The plan will provide evidence that the SBC will exercise management direction and control of the performance of the STTR effort, including situations in which the PI may be an employee of the RI. Not less than 40 percent of the work (amount requested including cost sharing, less fee, if any) is to be performed by the SBC as the prime contractor, and not less than 30 percent of the work is to be performed by the RI.

Part 5: Related R/R&D. Describe significant current and/or previous R/R&D that is directly related to the proposal including any conducted by the PI or by the offeror. Describe how it relates to the proposed effort and any planned coordination with outside sources. The offeror must persuade reviewers of his or her awareness of key recent R/R&D conducted by others in the specific subject area. At the offeror's option, this section may include concise bibliographic references in support of the proposal if they are confined to activities directly related to the proposed work.

Part 6: Key Personnel and Bibliography of Directly Related Work. Identify key personnel involved in Phase I activities whose expertise and functions are essential to the success of the project. Provide bibliographic information including directly related education and experience.
The PI is considered key to the success of the effort and must make a substantial commitment to the project. The following requirements are applicable:

Functions. The functions of the PI are: planning and directing the project; leading it technically and making substantial personal contributions during its implementation; serving as the primary contact with NASA on the project; and ensuring that the work proceeds according to contract agreements. Competent management of PI functions is essential to project success. The Phase I proposal shall describe the nature of the PI's activities and the amount of time that the PI will personally apply on the project. The amount of time the PI proposes to spend on the project must be acceptable to the NASA contracting officer.

Qualifications. The qualifications and capabilities of the proposed PI and the basis for PI selection are to be clearly presented in the proposal. NASA has the sole right to accept or reject a substitute PI based on factors such as education, experience, demonstrated ability and competence, and any other evidence related to the specific assignment.

Eligibility. This part shall also establish and confirm the eligibility of the PI (Section 1.5.3), and indicate the extent to which other proposals recently submitted or planned for submission in 2001 and existing projects commit the time of PI concurrently with this proposed activity. Any attempt to circumvent the restriction on PIs working more than half-time for an academic or a non-profit organization by substituting an ineligible PI will result in rejection of the proposal.

Part 7: Relationship with Phase II or Future R/R&D. State the anticipated results of the proposed R/R&D effort if the project is successful (through Phase I and Phase II). Discuss the significance of the Phase I effort in providing a foundation for the Phase II R/R&D continuation.

Part 8: Company Information and Facilities. Provide adequate information to allow the evaluators to assess the ability of the offeror to carry out the proposed Phase I and projected Phase II and Phase III activities. The offeror should describe the relevant facilities and equipment, their availability, and those to be acquired, to support the proposed activities. NASA will not fund the purchase of equipment, instrumentation, or facilities under Phase I contracts as a direct cost. Special tooling may be allowed. (Section 5.17)

The capability of the offeror to perform the proposed activities and bring a resulting product or service to market must be indicated. Qualifications of the offeror in marketing related products or services or in raising capital should be presented.

Note: If an offeror requires the use of any award funds for Government facilities, a statement, describing the uniqueness of the facility and its availability to the offeror at specified times, signed by the appropriate Government official must be included with the proposal.

Part 9: Subcontracts and Consultants. The SBC may establish business arrangements with other entities or individuals to participate in performance of the proposed R/R&D effort. The offeror must describe all subcontracting or other business arrangements, and identify the relevant organizations and/or individuals with whom arrangements are planned. The expertise to be provided by the entities must be described in detail, as well as the functions, services, number of hours and labor rates, and their extent of the effort. The proposal must include a signed statement by each participating organization or individual that they will be available at the times required for the purposes and extent of effort described in the proposal. Failure to provide certification(s) may result in rejection of the proposal. Subcontractors' and consultants' work must be performed in the United States.

SBIR

The proposed business arrangements must not exceed one-third of the research and/or analytical work (amount requested including cost sharing if any, less fee, if any).

STTR

The proposed business arrangements with individuals or organizations other than the RI must not exceed 30 percent of the work (amount requested including cost sharing if any, less fee, if any).

Part 10: Commercial Applications Potential. The Phase I proposal shall forecast the commercial potential of the project assuming success through Phase II. The proposer will be required to address the commercial, non-NASA applications in detail in the Phase II proposal (Sections 3.3 and 4.2.2).

Part 11: Similar Proposals and Awards. A firm may elect to submit proposals for essentially equivalent work under other federal program solicitations. However, NASA will not fund duplicate proposals for essentially equivalent work under any Government program. The offeror will inform NASA of related proposals and awards and clearly state whether the SBC has submitted currently active proposals for similar work under other Federal Government program solicitations or intends to submit proposals for such work to other agencies. For all such cases, the following information is required:

(1) The name and address of the agencies to which proposals have been or will be submitted, or from which awards have been received;
(2) Dates of such proposal submissions or awards;
(3) Title, number, and date of solicitations under which proposals have been or will be submitted or awards received;
(4) The specific applicable research topic for each such proposal submitted or award received;
(5) Titles of research projects;
(6) Name and title of the PI/project manager for each proposal that has been or will be submitted, or from which awards have been received.

Note: All eleven (11) parts must be included. Parts that are not applicable must be included and marked **"Not Applicable."**

3.2.5 Proposed Budget

Summary Budget (Form 9C). The offeror shall complete the Summary Budget, following the instructions provided with the form (Section 9) and include it and any explanation sheets, if needed, as the last page(s) of the proposal. Information shall be submitted to explain the offeror's plans for use of the requested funds to enable NASA to determine whether the proposed budget is fair and reasonable.

Property. Proposed costs for materials may be included. "Materials" means property that may be incorporated or attached to a deliverable end item or that may be consumed or expended in performing the contract. It includes assemblies, components, parts, raw materials, and small tools that may be consumed in normal use. Any purchase of equipment or products under a SBIR/STTR contract using NASA funds should be American-made to the extent possible. NASA will not fund facility acquisition under Phase I as a direct cost (Section 5.17).

Travel. Travel during Phase I is not normally allowed to prove technical merit and feasibility of the proposed innovation. However, where the offeror deems travel to be essential for these purposes, it is necessary to limit it to one person, one trip to the sponsoring NASA installation. Proposed travel must be described as to purpose and benefits in proving feasibility, and is subject to negotiation and approval by the contracting officer. Trips to conferences are not allowed under the Phase I contract.

Profit. A profit or fee may be included in the proposed budget as noted in Section 5.12.

Cost Sharing. See Section 5.11.

3.2.6 Cooperative Agreement (Applicable for STTR proposals only)

The Cooperative Agreement (not to be confused with the Allocation of Rights Agreement) shall be a single page document (see example in Section 9) signed by the SBC and the RI. This agreement counts toward the 25-page limit.

3.2.7 Addendum (Applicable for SBIR awards only)

The Small Business Administration requires offerors, who have received more than 15 Phase II awards from all agencies in the prior 5 fiscal years, to report those awards and their progress toward commercialization. The listing of awards shall be included in a separate "Addendum: Phase II History" that ***will not*** be counted against the Phase I 25-page proposal limit. The Addendum should be concise. Information for each Phase II contract shall include:

(1) Name of awarding agency
(2) Date of award and date of completion
(3) Funding agreement number and amount
(4) Topic or subtopic name
(5) Project title
(6) Sources, dates and amounts of federal and/or private sector Phase III follow-on funding agreements
(7) Post-Phase II commercialization activities, including development, marketing, sales, and projections

3.3 Phase II Proposal Requirements

3.3.1 General Requirements

The Phase I contract will serve as a request for proposal (RFP) for the Phase II follow-on project. Phase II proposals are more comprehensive than those required for Phase I. Phase II proposals are required to be submitted electronically by utilizing the electronic handbook system hosted on the NASA SBIR homepage (http://sbir.nasa.gov). Submission of a Phase II proposal is strictly voluntary and NASA assumes no responsibility for any proposal preparation expenses.

Note: The Cooperative Research established with a specific RI in STTR Phase I contracts shall continue with the same RI in Phase II.

Page Limitation. A Phase II proposal shall not exceed a total of 50 standard 8 1/2 x 11 inch (21.6 x 27.9 cm) pages. A page is defined as a single side of a piece of paper. All parts required in Section 3.3.2 will be included within this total. Each page shall be numbered consecutively at the bottom. Margins should be 1.0 inch (2.5 cm). **Proposals exceeding the 50-page limitation will be rejected during administrative screening.**

Type Size. No type size smaller than 10 point is to be used for text or tables, except as legends on reduced drawings. Proposals prepared with smaller font sizes will be rejected without consideration.

Classified Information. NASA does not accept proposals that contain classified information.

3.3.2 Proposal Contents.

Proposals shall be prepared in the following order. Failure to include any requested information in the proposal may make it non-responsive to the RFP. Budget data should be strictly limited to Part 13. A proposal omitting any part will be considered non-responsive to this Solicitation and may be rejected during administrative screening. The proposal must consist of all 13 parts numbered and in the following order:

Part 1: Proposal Cover.

Part 2: Proposal Summary.

Part 3: Table of Contents.

Part 4: Results of the Phase I Project. Briefly describe how Phase I has proven the feasibility of the innovation, provided a rationale for both NASA and commercial applications, and demonstrated the ability of the offeror to conduct R/R&D.

Part 5: Technical Objectives, Approach and Work Plan. Define the specific objectives of the Phase II research and technical approach; and provide a work plan defining specific tasks, performance schedules, milestones, and deliverables.

Part 6: Company Information. Describe the capability of the firm to carry out Phase II and Phase III activities including its organization, operations, number of employees, R/R&D capabilities, and experience relevant to the work proposed.

Part 7: Facilities and Equipment. This section shall provide adequate information to allow the evaluators to assess the ability of the SBC to carry out the proposed Phase II activities. The offeror should describe the relevant facilities and equipment currently available, and those to be purchased, to support the proposed activities. NASA will not fund the acquisition of equipment, instrumentation, or facilities under Phase II contracts as a direct cost. Special tooling may be allowed. (Section 5.17)

If an offeror proposes the use of unique or one-of-a-kind Government facilities, a statement describing the uniqueness of the facility and its availability to the offeror at specified times, signed by the appropriate Government official must be included with the proposal. Proposals lacking this signed statement may be rejected without evaluation.

Note: If the proposal does not require the use of Government facilities or equipment, the offeror shall so state in this part of the proposal.

Part 8: Key Personnel. Identify the key personnel for the project, confirm their availability for Phase II, and discuss their qualifications in terms of education, work experience, and accomplishments relevant to the project.

Part 9: Subcontracts and Consultants. Describe in detail any subcontract, consultant, or other business arrangements involving participation in performance of the proposed R/R&D effort and provide written evidence of their availability for the project. The proposal must include a commitment from each subcontractor and/or consultant that they will be available at the times required for the purposes and extent of effort described in the proposal. Subcontractors' and consultants' work must be performed in the United States. Failure to provide subcontractor/consultant commitments may result in rejection of proposal.

SBIR Phase II Proposal	STTR Phase II Proposal
A minimum of one-half of the work (contract cost less profit) must be performed by the proposing SBC.	A minimum of 40 percent of the work must be performed by the proposing SBC and 30 percent by the RI.

Part 10: Commercialization and Phase III Plans. Describe plans for commercialization (Phase III) in terms of each of the following areas:

(1) Product or Service Commercial Feasibility: Provide a description of the (a) contemplated commercial product and/or service, the corresponding commercial venture, and the unique competitive advantage of both; and (b) technical obstacles to commercial applications, as well as plans to address them.

(2) Market Feasibility and Competition: Describe: (a) the target market niche including the distinction between U.S. Government and other markets; (b) estimated potential market size in terms of revenues to be realized by the offer from U.S. Government markets and, separately, from other markets; (c) competitive environment in terms of present and likely competing similar and alternative technologies, and corresponding competing domestic and foreign entities; (d) significant developments within the targeted business sector; and (e) offeror's ability, if any, to protect relevant technology with patents or rights to exclusive access.

(3) Strategic Relevance to the Offeror: Describe the relevance of the targeted commercial venture to the offeror's: (a) current business segments; (b) relative position with respect to its competitors; and (c) strategic planning for the next 5 years.

(4) Key Management, Technical Personnel and Organizational Structure: Describe: (a) the skills and experience of key management and technical personnel relevant to bringing innovative technology to commercial application, (b) current organizational structure, and (c) plans and timeline for obtaining the balance of all necessary key business development expertise and other staffing requirements.

(5) Production and Operations: Describe: (a) business development progress to date regarding the contemplated commercial venture; (b) obstacles, plans, and associated milestones regarding all key business development elements; and (c) sources and components of private physical resources committed to date and plans for obtaining the balance of the necessary physical resources.

(6) Financial Planning: Describe: (a) the amounts and sources of private financial resources expended and committed to date with respect to the technology development project, and with respect to business development of the targeted commercial venture; (b) significant requirements of potential investors, creditors, and insurers of the venture; (c) proforma statement of cash flow with respect to the targeted commercial venture that includes best estimates of at least the following major components and timing thereof: capital investment, revenues, principal and interest payments, depreciation of relevant assets, other operating expenses; and (d) evidence of the offeror's current financial strength (audited or unaudited financial statements may be appended to address this).

Part 11: Capital Commitments Supporting Phase II and Phase III. Describe and document capital commitments from non-SBIR/STTR sources or from internal SBC funds for pursuit of Phase II and Phase III. Offerors for Phase II contracts are strongly urged to obtain non-SBIR/STTR funding support commitments for follow-on Phase III activities and additional support of Phase II from parties other than the proposing firm. Funding support commitments must provide that a specific, substantial amount will be made available to the firm to pursue the stated Phase II and/or Phase III objectives. They must indicate the source, date, and conditions or contingencies under which the funds will be made available. Alternatively, self-commitments of the same type and magnitude that are required from outside sources can be considered. If Phase III will be funded internally, offerors should describe their financial position.

Evidence of funding support commitments from outside parties must be provided in writing and should accompany the Phase II proposal. Letters of commitment should specify available funding commitments, other resources to be provided, and any contingent conditions. Expressions of technical interest by such parties in the Phase II research or of potential future financial support are insufficient and will not be accepted as support commitments by NASA.

Part 12: Related R/R&D. Describe R/R&D related to the proposed work and affirm that the stated objectives have not already been achieved and that the same development is not presently being pursued elsewhere under contract to the Federal Government.

Part 13: Proposal Pricing. Special instructions for pricing the Phase II proposal will be presented in the Phase-I contract and may be provided by the contracting officer.

4. Method of Selection and Evaluation Criteria

4.1 Phase I Proposals

Proposals judged to be responsive to the administrative requirements of this Solicitation and having a reasonable potential of meeting a NASA need, as evidenced by the technical abstract included in the Proposal Summary (Form 9B), will be evaluated on a competitive basis.

4.1.1 Evaluation Process. Proposals should provide all information needed for complete evaluation and evaluators are not expected to seek additional information. Evaluations will be performed by NASA scientists and engineers and by qualified experts outside of NASA (including industry, academia, and other Government agencies) as required to determine or verify the merit of a proposal. Offerors should not assume that evaluators are acquainted with the firm, key individuals, or with any experiments or other information. Any pertinent references or publications should be noted in Part 5 of the technical proposal.

4.1.2 Phase I Evaluation Criteria. NASA will give primary consideration to the scientific and technical merit and feasibility of the proposal and its benefit to NASA. Each proposal will be judged and scored on its own merits using the factors described below:

Factor 1. Scientific/Technical Merit and Feasibility
The proposed R/R&D effort will be evaluated on whether it offers a clearly innovative and feasible technical approach to the NASA problem area described in the subtopic. Specific objectives, approaches and plans for developing and verifying the innovation must demonstrate a clear understanding of the problem and the current state-of-the-art. The degree of understanding and significance of the risks involved in the proposed innovation must be presented.

Factor 2. Experience, Qualifications and Facilities
The technical capabilities and experience of the PI or project manager, key personnel, staff, consultants and subcontractors, if any, are evaluated for consistency with the research effort and their degree of commitment and availability. The necessary instrumentation or facilities required must be shown to be adequate and any reliance on external sources, such as Government Furnished Equipment or Facilities, addressed (Section 5.17).

Factor 3. Effectiveness of the Proposed Work Plan
The work plan will be reviewed for its comprehensiveness, effective use of available resources, cost management and proposed schedule for meeting the Phase I objectives. The methods planned to achieve each objective or task should be discussed in detail.

STTR: The clear delineation of the responsibilities of the SBC and RI for the success of the proposed cooperative R/R&D effort will be evaluated. The offeror must demonstrate the ability to organize for effective conversion of intellectual property into products or services of value to NASA and the commercial

Factor 4. Commercial Merit and Feasibility
The proposal will be evaluated for any potential commercial applications in the private sector or for use by the Federal Government.

Scoring of Factors and Weighting: Factors 1, 2, and 3 will be scored numerically with Factor 1 worth 50 percent and Factors 2 and 3 each worth 25 percent. The sum of the scores for Factors 1, 2, and 3 will comprise the Technical Merit score. The score for Commercial Merit will be in the form of an adjectival rating (Excellent, Very Good, Average, Below Average, Poor). For Phase 1 proposals, Technical Merit carries more weight than Commercial Merit.

4.1.3 Selection. After a proposal is reviewed based on the stated evaluation criteria, it will be ranked relative to all other proposals. Selection decisions will consider the recommendations from all Centers, Strategic Enterprises, overall NASA priorities, and program balance. The Source Selection Official has the final authority for choosing the specific proposals for contract negotiation.

The list of selections will be posted on the NASA SBIR/STTR web site **(http://sbir.nasa.gov)**. All firms will receive a formal notification letter. Selected firms will be notified of the designated contracting officer at the NASA Center responsible for negotiating the Phase I contract.

4.1.4 Allocation of Rights Agreement (Applicable for STTR awards only). After being selected for Phase I contract negotiations, but before the contract starts, the offeror shall, if requested, provide to the Contracting Officer at the managing NASA Center, a completed **Allocation of Rights Agreement (ARA),** which has been signed by authorized representatives of the SBC, RI and subcontractors and consultants, as applicable. The ARA shall state the allocation of intellectual property rights with respect to the proposed STTR activity and planned follow-on research, development and/or commercialization.

4.2 Phase II Proposals

4.2.1 Evaluation Process. The Phase II evaluation process is similar to the Phase I process. Each proposal will be reviewed by NASA scientists and engineers and by qualified experts outside of NASA as needed. In addition, those proposals with high technical merit will be reviewed for commercial merit. NASA uses a peer review panel to evaluate commercial merit. Panel membership will include non-NASA personnel expert in business development and technology commercialization.

4.2.2 Evaluation Factors. The evaluation of Phase II proposals under this Solicitation will apply the following factors:

Factor 1. Scientific/Technical Merit and Feasibility
The proposed R/R&D effort will be evaluated on its innovativeness, originality, and technical payoff potential if successful, including the degree to which Phase I objectives were met, the feasibility of the innovation, and whether the Phase I results indicate a Phase II project is appropriate.

Factor 2. Future Importance and Value to NASA
The eventual value of the product, process, or technology results to the NASA mission will be assessed.

Factor 3. Capability of the Small Business Concern
NASA will assess the capability of the SBC to conduct Phase II based on (a) the validity of the project plans for achieving the stated goals; (b) the qualifications and ability of the project team (Principal Investigator/ Project Manager, company staff, consultants and subcontractors) relative to the proposed research; and (c) the availability of any required equipment and facilities.

Factor 4. Commercial Potential. Consideration will be given to the following:

(1) Commercial potential of the technology: This includes an assessment of the offeror’s ability to demonstrate: (a) a specific, well-defined commercial product or service based on the technology to be developed; (b) a realistic target market niche of sufficient size; (c) that the targeted commercial product or service has strong potential for uniquely meeting a well-defined need within the target market niche; and (d) a commitment of significant private financial, physical, and technical personnel resources.

(2) Demonstrated commercial intent of the offeror: This includes an assessment of: (a) the importance of the targeted commercial venture to the offeror's current business and strategic planning; (b) a targeted commercial venture that does not rely on continued U.S. Government markets; and (c) the adequacy of all resource commitments for Phase III development of the technology to a state of readiness for commercial application.

(3) Capability of the offeror to bring successfully developed technology to commercial application: This includes assessment of the offeror's ability to demonstrate: (a) the offeror's past success in bringing SBIR/STTR and other innovative technologies to commercial application; (b) well-thought-out business planning; (c) strong likelihood of the offeror's bringing the remaining necessary private financial, physical, personnel and other resources to bear in a timely way to achieve commercial application of the technology in the not too distant term subsequent to Phase II; and (d) the strength of the current and continued financial viability of the offeror.

In applying these commercial criteria, NASA will assess proposal information in terms of credibility, objectivity, reasonableness of key assumptions, independent corroborating evidence, internal consistency, demonstrated awareness of key risk areas and critical business vulnerabilities, and other indicators of sound business analysis and judgment.

4.2.3 Evaluation and Selection. Factors 1, 2, and 3 will be scored numerically with Factor 1 worth 50 percent and Factors 2 and 3 each worth 25 percent. The sum of the scores for Factors 1, 2, and 3 will comprise the Technical Merit score. Proposals receiving high numerical scores will be evaluated and rated for their commercial potential using the criteria listed in Factor 4 and by applying the same adjectival ratings as set forth for Phase I proposals.

Each NASA Installation managing Phase I projects will use these factors to evaluate the Phase II proposals it receives that are responsive to the Phase II RFP. Final selections will be based on recommendations from all Installations and Strategic Enterprises; assessments of project value to NASA's overall programs and plans; and any other evaluations or assessments (particularly of commercial potential) that may become available to the Source Selection Official.

Note: Companies with Prior NASA SBIR Awards

NASA has instituted a comprehensive commercialization survey/data gathering process for companies with prior NASA SBIR awards. Information received from SBIR companies completing the survey is kept confidential, and will not be made public except in broad aggregate, with no company specific attribution.

Responding to the survey is strictly voluntary. However, the SBIR Source Selection Official does see the information contained within the survey as adding to the program's ability to use past performance in decision making.

If you have not completed a survey, or if you would like to update a previously submitted response, please go on-line at http://sbir.nasa.gov/SBIR/survey.html or contact Jack Yadvish at NASA Headquarters by email at jyadvish@mail.hq.nasa.gov, or phone at 202-358-1981.

4.3 Debriefing of Unsuccessful Offerors

After Phase I and Phase II selection decisions have been announced, debriefings for unsuccessful proposals will be available to the offeror's corporate official or designee via e-mail. Telephone requests for debriefings will not be accepted. Debriefings are not opportunities to reopen selection decisions. They are intended to acquaint the offeror with perceived strengths and weaknesses of the proposal and perhaps identify constructive future action by the offeror.

Debriefings will not disclose the identity of the proposal evaluators nor provide proposal scores, rankings in the competition, or the content of, or comparisons with other proposals.

4.3.1 Phase I Debriefings. For Phase I proposals, any request for a debriefing must be made via e-mail to sbir@reisys.com, within 60 days after the selection announcement. Late requests will not be honored.

4.3.2 Phase II Debriefings. To request debriefings on Phase II proposals, offerors must request via e-mail to the Procurement Point of Contact at the appropriate NASA Center (not the SBIR/STTR Program Manager) within 60 days after selection announcement. Late requests will not be honored.

5. Considerations

5.1 Awards

5.1.1 Availability of Funds. Both Phase I and Phase II awards are subject to availability of funds. NASA has no obligation to make any specific number of Phase I or Phase II awards based on this Solicitation, and may elect to make several or no awards in any specific technical topic or subtopic.

SBIR

- NASA plans to announce the selection of approximately 300 proposals resulting from this Solicitation, for negotiation of Phase I contracts with values not exceeding $70,000. Following contract negotiations and awards, Phase I contractors will have up to 6 months to carry out their programs, prepare their final reports, and submit Phase II proposals.
- NASA anticipates that approximately 40 percent of the successfully completed Phase I projects from the SBIR 2001 Solicitation will be selected for Phase II. Phase II agreements are fixed-price contracts with performance periods not exceeding 24 months and funding not exceeding $600,000.

STTR

- NASA plans to announce the selection of approximately 20 proposals resulting from this Solicitation, for negotiation of Phase I contracts with values not exceeding $100,000. Following contract negotiations and awards, Phase I contractors will have up to 12 months to carry out their programs, prepare their final reports, and submit Phase II proposals.
- NASA anticipates that approximately 35 percent of the successfully completed Phase I projects from the STTR 2001 Solicitation will be selected for Phase II. Phase II agreements are fixed-price contracts with performance periods not exceeding 24 months and funding not exceeding $500,000.

5.1.2 Contracting. Fixed-price contracts will be issued for both Phase I and Phase II awards. Simplified contract documentation is employed; however, SBCs selected for award can reduce processing time by examining the procurement documents, submitting signed representations and certifications, and responding to the Contracting Officer in a timely manner. NASA will make Phase I model contract and other documents available to the public on the NASA SBIR/STTR homepage (http://sbir.nasa.gov) at the time of the selection announcement. **From the time of proposal selection until the award of a contract, only the Contracting Officer is authorized to commit the Government, and all communications must be through the Contracting Officer.**

Note: NASA is not responsible for any monies expended by the offeror before award of any contract resulting from this Solicitation.

5.2 Phase I Reporting

An interim progress report is required when the invoice is submitted at project mid-point in accordance with the payment schedule (Section 5.3). This report shall document progress made on the project and activities required for completion to provide NASA the basis for determining whether the payment is warranted.

A final report must be submitted to NASA upon completion of the Phase I R/R&D effort in accordance with contract provisions. It shall elaborate the project objectives, work carried out, results obtained, and assessments of technical merit and feasibility. The final report shall include a single page summary as the first page, in a format provided in the Phase I contract, identifying the purpose of the R/R&D effort and describing the findings and results, including the degree to which the Phase I objectives were achieved, and whether the results justify Phase II continuation. The potential applications of the project results in Phase III either for NASA or commercial purposes shall also be described. The proposal summary is to be submitted without restriction for NASA publication.

5.3 Payment Schedule for Phase I

Payments can be authorized as follows: one-third at the time of award, one-third at project mid-point after award, and the remainder upon acceptance of the final report by NASA. The first two payments will be made 30 days after receipt of valid invoices. The final payment will be made 30 days after acceptance of the final report, the New Technology Report, and other deliverables as required by the contract. Electronic funds transfer will be employed and offerors will be required to submit account data if selected for contract negotiations.

5.4 Proprietary Information

It is NASA's policy to use information (data) included in proposals for evaluation purposes only. Public release of information in any proposal submitted will be subject to existing statutory and regulatory requirements. If information consisting of a trade secret, proprietary commercial or financial information, or private personal information is provided in a proposal, NASA will treat in confidence the proprietary information provided the following legend appears on the title page of the proposal:

> "For any purpose other than to evaluate the proposal, this data shall not be disclosed outside the Government and shall not be duplicated, used, or disclosed in whole or in part, provided that if a funding agreement is awarded to the offeror as a result of or in connection with the submission of this data, the Government shall have the right to duplicate, use or disclose the data to the extent provided in the funding agreement. This restriction does not limit the Government's right to use information contained in the data if it is obtained from another source without restriction. The data subject to this restriction are contained in pages _____ of this proposal."

> **Note:** Do not label the entire proposal proprietary. The Proposal Summary (Form 9B) should not contain proprietary information**.**

5.5 Non-NASA Reviewers

In addition to Government personnel, NASA, at its discretion and in accordance with 18-15.207-71 of the NASA FAR Supplement, may utilize qualified individuals from outside the Government in the proposal review process. Any decision to obtain an outside evaluation shall take into consideration requirements for the avoidance of organizational or personal conflicts of interest and the competitive relationship, if any, between the prospective contractor or subcontractor(s) and the prospective outside evaluator. Any such evaluation will be under agreement with the evaluator that the information (data) contained in the proposal will be used only for evaluation purposes and will not be further disclosed.

5.6 Release of Proposal Information

In submitting a proposal, the offeror agrees to permit the Government to disclose publicly the information contained on the Proposal Cover (Form 9A) and the Proposal Summary (Form 9B). Other proposal information (data) is considered to be the property of the offeror, and NASA will protect it from public disclosure to the extent permitted by law.

5.7 Final Disposition of Proposals

The Government retains ownership of proposals accepted for evaluation, and such proposals will not be returned to the offeror. Copies of all evaluated Phase I proposals will be retained for one year after the Phase I selections have been made, after which time unsuccessful proposals will be destroyed. Successful proposals will be retained in accordance with contract file regulations.

5.8 Rights in Data Developed Under SBIR/STTR Contracts

Rights to data used in, or first produced under, any Phase I or Phase II contract are specified in the clause at FAR 52.227-20, Rights in Data--SBIR/STTR Program. The clause provides for rights consistent with the following:

5.8.1 Non-Proprietary Data. Some data of a general nature are to be furnished to NASA without restriction (i.e., with unlimited rights) and may be published by NASA. These data will normally be limited to the project summaries accompanying any periodic progress reports and the final reports required to be submitted. The requirement will be specifically set forth in any contract resulting from this Solicitation.

5.8.2 Proprietary Data. When data that is required to be delivered under a SBIR/STTR contract qualifies as "proprietary," *i.e.*, either data developed at private expense that embody trade secrets or are commercial or financial and confidential or privileged, or computer software developed at private expense that is a trade secret, the contractor, if the contractor desires to continue protection of such proprietary data, shall not deliver such data to the Government, but instead shall deliver form, fit, and function data.

5.8.3 Non-Disclosure Period. The Government, for a period of 4 years from acceptance of all items to be delivered under a SBIR/STTR contract, shall use the data, *i.e.*, data first produced by the contractor in performance of the contract, where such data are not generally known, and which data without obligation as to its confidentiality have not been made available to others by the contractor or are not already available to the Government, agrees to use these data for Government purposes. These data shall not be disclosed outside the Government (including disclosure for procurement purposes) during the 4-year period without permission of the contractor, except that such data may be disclosed for use by support contractors under an obligation of confidentiality. After the 4-year period, the Government has a royalty-free license to use, and to authorize others to use on its behalf, these data for Government purposes, but the Government is relieved of all disclosure prohibitions and assumes no liability for unauthorized use by third parties.

5.9 Copyrights

Subject to certain licenses granted by the contractor to the Government, the contractor receives copyright to any data first produced by the contractor in the performance of a SBIR/STTR contract.

5.10 Patents

The contractor may normally elect title to any inventions made in the performance of a SBIR/STTR contract. The Government receives a nonexclusive license to practice or have practiced for or on behalf of the Government each such invention throughout the world. To the extent authorized by 35 U.S.C. 205, the Government will not make public any information disclosing such inventions for a reasonable time to allow the contractor to file a patent application.

Costs associated with patent applications are not allowable.

5.11 Cost Sharing

Cost sharing is permitted, but not required for proposals under this Solicitation. Cost sharing, if included, should be shown in the summary budget but not in items labeled "AMOUNT REQUESTED." No profit will be paid on the cost-sharing portion of the contract.

STTR: If cost sharing is proposed, then these added funds shall be included in the 40/30 work percentage distribution and reflected in the Summary Budget (Form 9C).

5.12 Profit or Fee

Both Phase I and Phase II contracts may include a reasonable profit. The reasonableness of proposed profit is determined by the Contracting Officer during contract negotiations.

5.13 Joint Ventures and Limited Partnerships

Both joint ventures and limited partnerships are permitted, provided the entity created qualifies as a SBC in accordance with the definition in Section 2.1. A statement of how the workload will be distributed, managed, and charged should be included in the proposal. A copy or comprehensive summary of the joint venture agreement or partnership agreement should be appended to the proposal. This will not count as part of the 25-page limit for the Phase I proposal.

5.14 Similar Awards and Prior Work

If an award is made pursuant to a proposal submitted under either SBIR or STTR Solicitation, the firm will be required to certify that it has not previously been paid nor is currently being paid for essentially equivalent work by any agency of the Federal Government. Failure to acknowledge or report similar or duplicate efforts can lead to the termination of contracts or criminal or civil penalties.

5.15 Contractor Commitments

Upon award of a contract, the contractor will be required to make certain legal commitments through acceptance of numerous clauses in the Phase I contract. The outline that follows illustrates the types of clauses that will be included. This is not a complete list of clauses to be included in Phase I contracts, nor does it contain specific wording of these clauses. Copies of complete provisions will be made available prior to contract negotiations.

5.15.1 Standards of Work. Work performed under the contract must conform to high professional standards. Analyses, equipment, and components for use by NASA will require special consideration to satisfy the stringent safety and reliability requirements imposed in aerospace applications.

5.15.2 Inspection. Work performed under the contract is subject to Government inspection and evaluation at all reasonable times.

5.15.3 Examination of Records. The Comptroller General (or a duly authorized representative) shall have the right to examine any directly pertinent records of the contractor involving transactions related to the contract.

5.15.4 Default. The Government may terminate the contract if the contractor fails to perform the contracted work.

5.15.5 Termination for Convenience. The contract may be terminated by the Government at any time if it deems termination to be in its best interest, in which case the contractor will be compensated for work performed and for reasonable termination costs.

5.15.6 Disputes. Any dispute concerning the contract that cannot be resolved by mutual agreement shall be decided by the contracting officer with right of appeal.

5.15.7 Contract Work Hours. The contractor may not require a non-exempt employee to work more than 40 hours in a workweek unless the employee is paid for overtime.

5.15.8 Equal Opportunity. The contractor will not discriminate against any employee or applicant for employment because of race, color, religion, age, sex, or national origin.

5.15.9 Affirmative Action for Veterans. The contractor will not discriminate against any employee or applicant for employment because he or she is a disabled veteran or veteran of the Vietnam era.

5.15.10 Affirmative Action for Handicapped. The contractor will not discriminate against any employee or applicant for employment because he or she is physically or mentally handicapped.

5.15.11 Officials Not to Benefit. No member of or delegate to Congress shall benefit from a SBIR or STTR contract.

5.15.12 Covenant Against Contingent Fees. No person or agency has been employed to solicit or to secure the contract upon an understanding for compensation except bona fide employees or commercial agencies maintained by the contractor for the purpose of securing business.

5.15.13 Gratuities. The contract may be terminated by the Government if any gratuities have been offered to any representative of the Government to secure the contract.

5.15.14 Patent Infringement. The contractor shall report to NASA each notice or claim of patent infringement based on the performance of the contract.

5.15.15 American-Made Equipment and Products. Equipment or products purchased under a SBIR or STTR contract must be American-made whenever possible.

5.16 Additional Information

5.16.1 Precedence of Contract Over Solicitation. This Program Solicitation reflects current planning. If there is any inconsistency between the information contained herein and the terms of any resulting SBIR/STTR contract, the terms of the contract are controlling.

5.16.2 Evidence of Contractor Responsibility. Before award of a SBIR or STTR contract, the Government may request the offeror to submit certain organizational, management, personnel, and financial information to establish responsibility of the offeror. Contractor responsibility includes all resources required for contractor performance, i.e., financial capability, work force, and facilities.

5.16.3 Central Contractor Registration: Offerors should be aware of the requirement to register in the Central Contractor Registration database prior to contract award. **To avoid a potential delay in contract award, offerors are strongly encouraged to register prior to submitting a proposal.**

The Central Contractor Registration (CCR) database is the primary repository for contractor information required for the conduct of business with NASA. It is maintained by the Department of Defense. To be registered in the CCR database, all mandatory information, which includes the DUNS or DUNS+4 number, and a CAGE code, must be validated in the CCR system. The DUNS number or Data Universal Number System is a 9-digit number assigned by Dun and Bradstreet Information Services to identify unique business entities. The DUNS+4 is similar, but includes a 4-digit suffix that may be assigned by a parent (controlling) business concern. The CAGE code or Commercial Government and Entity Code is assigned by the Defense Logistics Information Service (DLIS) to identify a commercial or Government entity.

The DoD has established a goal of registering an applicant in the CCR database within 48 hours after receipt of a complete and accurate application via the Internet. However, registration of an applicant submitting an application through a method other than the Internet may take up to 30 days. Therefore, offerors that are not registered should consider applying for registration immediately upon receipt of this solicitation. Offerors and contractors may obtain information on CCR registration and annual confirmation requirements via the Internet at http://www.ccr2000.com or by calling 888-CCR-2423 (888-227-2423).

5.17 Property

In accordance with the Federal Acquisition Regulations (FAR) Part 45, it is NASA's policy not to provide facilities (capital equipment, tooling, test and computer facilities, etc.) for the performance of work under contract. An SBC will furnish its own facilities to perform the proposed work as an indirect cost to the contract. Special tooling required for a project may be allowed as a direct cost.

When an SBC cannot furnish its own facilities to perform required tasks, an SBC may propose to acquire the use of commercially available facilities. Rental or lease costs may be considered as direct costs as part of the total funding for the project. If unique requirements force an offeror to acquire facilities under a NASA contract, they will be purchased as Government Furnished Equipment (GFE) and titled to the Government.

An offeror may propose the use of unique or one-of-a-kind NASA facilities if essential for the research. Offerors requiring a NASA facility must clearly document and certify that there is no commercially available facility to perform the R&D. It may be difficult, however, to ensure availability, and non-availability may lead to non-selection. Should an offeror propose the use of unique or one-of-a-kind NASA facilities essential for the R/R&D, an agreement with the responsible installation is required and costs for their use will be determined by the installation. These costs may be chargeable in accordance with the Government property clause of the contract. Total contract costs must not exceed the Phase I and Phase II funding limits given in this Solicitation (Section 5.1).

6. Submission of Proposals

6.1 The Submission Process

6.1.1 Submission Requirements. NASA utilizes an electronic process for management of the SBIR/STTR programs. This management approach requires that a proposing firm have Internet access and an e-mail address.

6.1.2 What Needs to Be Submitted. A proposal submission is comprised of two parts:

(1) **Internet Submission.** The entire proposal including Forms 9A, 9B and 9C must be submitted via the Internet (http://sbir.nasa.gov). Firms may also submit an optional briefing chart, which is not included in the 25 page count. An example chart has been provided in Appendix B.
(2) **Postal Submission**. Postal submission includes an original signed proposal with all required forms.

Note: Firms not able to obtain Internet access must request an exemption by calling 301-286-5661 or 301-937-0888 by Wednesday, May 23, 2001.

Note: Other forms of submissions such as fax, diskette, or e-mail attachments are not acceptable.

6.2 Internet Submission

6.2.1 Electronic Technical Proposal Preparation. The term "Technical Proposal" refers to the part of the submission as described in Section 3.2.4.

Word Processor. NASA converts all technical proposal files to PDF format for evaluation purposes. Therefore, NASA requests that technical proposals be submitted in PDF format, and encourages companies to do so. Other acceptable formats for PC are AmiPro, ClarisWorks for Windows, MS Works, Text, MS Word, WordPerfect, and Postscript. For Macintosh, the acceptable formats are ClarisWorks, MS Works, MacWrite Pro, Text, MS Word, WordPerfect, and Postscript. Unix and TeX users please note that due to PDF difficulties with non-standard fonts, please output technical proposal files in DVI format.

Graphics. For reasons of space conservation and simplicity the offeror is encouraged, but not required, to embed graphics within the document. For graphics submitted as separate files, the acceptable file formats (and their respective extensions) are: Bit-Mapped (.bmp), Graphics Interchange Format (.gif), JPEG (.jpg), PC Paintbrush (.pcx), WordPerfect Graphic (.wpg), and Tagged-Image Format (.tif).

Limitations. While only the paper copy will be screened for administrative compliance, the various files comprising the electronic version are required to exactly reflect the paper version.

Virus Check. The offeror is responsible for performing a virus check on each submitted technical proposal. As a standard part of entering the proposal into the processing system, NASA will scan each submitted electronic technical proposal for viruses. **The detection, by NASA, of a virus on any submitted electronic technical proposal, may cause rejection of the proposal.**

6.2.2 Electronic Handbook. An Electronic Handbook for submitting proposals via the internet is hosted on the NASA SBIR/STTR Homepage (http://sbir.nasa.gov). The handbook will guide the firms through the various steps required for submitting a SBIR/STTR proposal and issue secure-user identification and passwords for each submission. Communication between NASA and the firm will be via a combination of electronic handbooks and e-mail.

Note: After the offeror has submitted Forms 9A, 9B, and 9C via the Internet, the offeror should use the handbook to print the three forms locally. These forms must be signed as appropriate and included in the postal

6.3 Postal Submission

Postal Submissions are comprised of one original signed paper copy of the proposal, including paper copies of all original forms (as stated in Section 3.2.2)

6.3.1 Physical Packaging Requirements for Paper Copy of Proposal. Do not use bindings or special covers. Staple the pages of the proposal in the upper left-hand corner only. Secure packaging is mandatory. NASA cannot process proposals damaged in transit. All items for any proposal must be sent in the same envelope. If more than one proposal is being submitted, each proposal must be in its own envelope, but all proposals may be sent in the same package. Do not send duplicate packages of any proposal as "insurance" that at least one will be received.

Note: A checklist is included in this Solicitation to assist the offeror in submitting a complete proposal. The checklist should not be submitted with the proposal.

6.3.2 Where to Send Proposals. All proposals that are mailed through the U.S. Postal Service first class, registered, or certified mail; proposals sent by express mail or commercial delivery services; or hand-carried proposals **must be** delivered to the following address between 8:00 a.m. and 5:00 p.m. EDT:

NASA SBIR/STTR Program Support Office
REI Systems, Inc
4041 Powder Mill Road
Suite 311
Calverton (Beltsville), MD 20705-3106

The telephone number 301-937-0888 may be used when required for reference by delivery services:

6.3.3 Deadline for Proposal Receipt. All proposal submissions (both internet and postal) must be received no later than 5:00 p.m. EDT on Wednesday, June 6, 2001 at the NASA SBIR/STTR Program Support Office. Any proposal received after that date and time shall be considered late and handled accordingly.

Note: The server/electronic handbook will not be available for internet submissions after 5:00 p.m. EDT on Wednesday, June 6, 2001.

6.4 Acknowledgment of Proposal Receipt

NASA will acknowledge receipt of proposals to the SBC Official's e-mail address as provided on the proposal cover sheet. If a proposal acknowledgment is not received within 14 days following the closing date of this Solicitation, the offeror should call NASA SBIR/STTR Program Support Office at 301-937-0888. Information about proposal status will not be available until final selections are announced.

6.5 Withdrawal of Proposals

Proposals may be withdrawn by written notice, signed by the designated SBC Official. Withdrawal notice must include proposal number and title.

7. Scientific and Technical Information Sources

7.1 NASA SBIR/STTR Homepage

Detailed information on NASA's SBIR/STTR Programs is available at: **http://sbir.nasa.gov.**

7.2 NASA Commercial Technology Network

The NASA Commercial Technology Network (NCTN) contains a significant amount of on-line information about the NASA Commercial Technology Program. The address for the NCTN homepage is: **http://nctn.hq.nasa.gov/**

7.3 NASA Technology Utilization Services

The **National Technology Transfer Center (NTTC)**, sponsored by NASA in cooperation with other Federal agencies, serves as a national resource for technology transfer and commercialization. NTTC has a primary role to get Government research into the hands of U.S. businesses. Its gateway services make it easy to access databases and to contact experts in your area of research and development. For further information, call 800-678-6882.

NASA's network of **Regional Technology Transfer Centers (RTTCs)** provides business planning and development services. However, NASA does not accept responsibility for any services these centers may offer in the preparation of proposals. RTTCs can be contacted directly as listed below to determine what services are available and to discuss fees charged. Alternatively, to contact any RTTC, call 800-472-6785.

Northeast:
Center for Technology Commercialization
Massachusetts Technology Park
1400 Computer Drive
Westboro, MA 01581-5054
Phone: 508-870-0042
URL: http://www.ctc.org

Mid-Atlantic:
Technology Commercialization Center, Inc.
12050 Jefferson Avenue
Newport News, VA 23606
Phone: 757-269-0025
URL: http://www.teccenter.org

Southeast:
Georgia Institute of Technology
151 6th Street
216 O'Keefe Building
Atlanta, GA 30332
Phone: 404-894-6786
URL: Currently Under Development

Mid-West:
Great Lakes Industrial Technology Center
Battelle Memorial Institute
25000 Great Northern Corporate Center, Suite 450
Cleveland, OH 44070-5310
Phone: 440-734-0094
URL: http://www.battelle.org/glitec

Mid-Continent:
Mid-Continent Technology Transfer Center
Texas Engineering Extension Service
Technology & Economic Development Division
College Station, TX 77843-8000
Phone: 409-845-2913
URL: http://www.mcttc.com/

Far-West:
Far-West Technology Transfer Center
University of Southern California
3716 South Hope Street, Suite 200
Los Angeles, CA 90007-4344
Phone: 800-642-2872
URL: http://www.usc.edu/dept/engineering/TTC/NASA

7.4 United States Small Business Administration

The Policy Directives for the SBIR/STTR Programs, which also state the SBA policy for this Solicitation, may be obtained from the following source. SBA information can also be obtained at: http://www.sba.gov/.

Office of Innovation, Research and Technology
U.S. Small Business Administration
409 Third Street, S.W.
Washington, D.C. 20416
Phone: 202-205-7701

7.5 National Technical Information Service

The **National Technical Information Service**, an agency of the Department of Commerce, is the Federal Government's central clearinghouse for publicly funded scientific and technical information. For information about their various services and fees, call or write:

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Phone: 800-553-6847
URL: http://www.ntis.gov

8. Research Topics for SBIR and STTR

8.1 SBIR Research Topics

Introduction

The SBIR Program Solicitation is aligned with the established NASA management structure of the Strategic Enterprises (http://www.nasa.gov).

The Enterprises identify, at the most fundamental level, what NASA does and for whom. Each Strategic Enterprise is analogous to a strategic business unit employed by private-sector companies to focus on and respond to their customers' needs. Each Strategic Enterprise has a unique set of goals, objectives, and strategies. Research topics and subtopics in this Solicitation are organized by the five NASA Strategic Enterprises:

Aerospace Technology
Biological and Physical Research
Earth Science
Human Exploration and Development of Space
Space Science

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8.1.1 AEROSPACE TECHNOLOGY

NASA's Aerospace Technology Enterprise pioneers the identification, development, verification, transfer, application, and commercialization of high-payoff aeronautics technologies. It seeks to promote economic growth and security and to enhance U.S. competitiveness through safe, superior, and environmentally compatible U.S. civil and military aircraft and through a safe, efficient national aviation system. In addition, the Enterprise recognizes that the space transportation industry can benefit significantly from the transfer of aviation technologies and flight operations to launch vehicles, the goal being reducing the cost of access to space. The Enterprise will work closely with its aeronautics customers, including U.S. industry, the Department of Defense, and the Federal Aviation Administration, to ensure that its technology products and services add value, are timely, and have been developed to the level where the customer can confidently make decisions regarding the application of those technologies.

http://www.hq.nasa.gov/office/aero

A1 Aviation Safety

NASA is responsible for conducting the research that, upon implementation, will contribute to an 80 percent reduction in aviation accidents by 2007, and a 90 percent reduction in aviation accidents by 2017 relative to 1997. Accomplishment of these goals requires technical advances in the following areas: (1) Increased safety for all aircraft flying in an atmospheric icing environment; (2) Prevention and/or mitigation of hazardous conditions during or after an aviation accident; (3) Enhanced flight deck situational awareness for the National Airspace System operators; (4) Automated on-line health management and data analysis for aircraft systems; (5) Innovative and commercially viable techniques for non-destructive evaluation and health monitoring of aircraft materials and structures.

A1.01 Flight Deck Situation Awareness and Crew Systems Technologies
Lead Center: LaRC
Participating Center(s): None

Information technology has and will continue to provide operational opportunities toward increasing the safe and efficient use of the Airspace System. Significant challenges associated with this evolving technology include maintaining or enhancing the situation awareness of system operators, developing user-centered technologies that facilitate human perception and interpretation and that counteract human information processing limitations and biases, and allowing for geographically and temporally distributed operators to work collaboratively.

NASA seeks highly innovative crew systems technologies that will maintain or enhance situation awareness and aid operator decision-making for improved aerospace safety and efficiency. These technologies and methods may take the form of tools, models, techniques, procedures, substantiated guidelines, prototypes, and devices. In addition, we seek tools and methods for measuring and analyzing human and group performance in complex, dynamic systems. Innovative and economically attractive approaches are sought to advance the current state-of-the-art in the following areas:

- Systems monitoring with sensitive informing, advisements, alerts, and aids for Airspace System operators that enhance situation awareness and improve aviation safety.
- Crew-centered systems design methods and technologies.
- Innovative crew-system interface technologies.
- Human-error reduction in aircraft operations and systems monitoring.
- Error tolerant flight deck systems including advanced displays, crew-system interfaces, and monitoring technologies.
- Human and group performance analysis methods and tools.
- Human performance measurement technologies for use in operational environments.
- Collaborative and distributive decision making among Airspace System operators.
- Integrated flight deck information systems and procedures.
- Decision support technologies and methods to assist Airspace System operators that enhance situation awareness and improve aviation safety.
- Artificial Intelligence technologies and concepts that monitor crew and aircraft performance to ensure appropriate levels of engagement, crew workload and situation awareness.
- Human-centered information technologies that enhance situation awareness and performance of less experienced Airspace System operators especially at critical times.
- Development of human-centered information technology for intuitive guidance queues in advanced concepts.
- Guidelines and measurement techniques that allow for successful assessment of the application of human-centered design principles to flight deck display concepts.

A1.02 Propulsion and Airframe Failure Data and Accident Mitigation
Lead Center: GRC
Participating Center(s): LaRC

NASA is concerned with the prevention of hazardous and accident conditions and the mitigation of their effects when they do occur. One particular emphasis is on fire. The prevention, detection, and suppression of fires are critical goals of accident mitigation. Aircraft fires represent a small number of actual accidents, but the number of fatalities due to in-flight, post-crash and on-ground fires is large.

A second emphasis is on crashworthiness. For all transport aircraft accidents, 45 percent of those which involve serious injuries or fatalities are survivable. Besides impact alone, survivability is often a function of the combined effects of subsequent fire and smoke. Technology is needed to further protect passengers from the effects of the crash or mitigate the after effects to allow the escape of passengers.

A third emphasis is on mitigating the safety risk and collateral damage due to unexpected failures of rotating components. Although the FAA mandates a blade containment and rotor unbalance requirement (FAR Part 33, section 33.94) as part of the airworthiness standards for (turbine) aircraft engines, there are substantial potential (aircraft-engine) system benefits to be gained by enabling safety assured, lighter weight, lower cost, and more damage tolerant designs for engine case/containment systems and associated (primary load path) structures.

A final emphasis for this Solicitation is on propulsion system health management in order to prevent or accommodate safety-significant malfunctions. Past advances in this area have helped improve the reliability and safety of aircraft propulsion systems. However, propulsion system component failures are still a contributing factor in numerous aircraft accidents and incidents. Advances in instrumentation, health monitoring algorithms, and fault accommodating logic are sought which help to further reduce the occurrence of and/or mitigate the effects of safety-significant propulsion system malfunctions.

With these four emphases in mind, products and technologies are sought to mitigate or prevent relevant accidents, to enhance human survivability in the event of an accident, and to monitor system health. Considerations should be made for affordability and retrofitability to the commercial transport, general aviation, and rotorcraft fleets. These include the following areas:

- Technology for fire prevention, detection, and suppression of potential in-flight fires in fuel tanks, insulation, cargo compartments, and other inaccessible locations.
- Technology to provide fuel tank vapor flammability reduction and on-board oxygen generation.
- Technology to minimize fire hazards in crashes and to prevent or delay fires. For example: fuel-system modifications to eliminate spills, and on-demand suppression while not presenting a weight or performance penalty.
- Design and injury criteria and dynamic analyses to enhance crash safety.
- Systems approach to crashworthy designs, which may include validated occupant/seat/structural interaction analyses.
- Energy-absorbing seat and structural concepts and materials.
- Technology for occupant protection in a crash, including advanced restraints and supplemental restraints.
- Advanced material/structural configuration concepts to prevent catastrophic failures of engine components, or to ensure fragment containment.
- Computational tools for analyzing blade-loss events and designing structural components/systems accordingly.
- Health management technologies such as advanced instrumentation, health monitoring algorithms, and fault accommodating logic, to predict, diagnose, and prevent safety significant propulsion system malfunctions.
- Low cost methods for failure prediction and testing of any of the above aircraft failure-prevention and mitigation technologies.
- Methods for integrating any of the above aircraft failure-prevention and mitigation technologies into existing or new aircraft.

A1.03 Automated On-Line Health Management and Data Analysis
Lead Center: DFRC
Participating Center(s): None

On-line health monitoring is a critical technology for improving transportation safety in the 21st century. Safe, affordable, and more efficient operation of aerospace vehicles requires advances in online health monitoring of vehicle subsystems and information monitoring from many sources over local/wide area networks. On-line health monitoring is a general concept involving signal-processing algorithms designed to support decisions related to safety, maintenance, or operating procedures. The concept of on-line emphasizes algorithms that minimize the time between data acquisition and decision-making.

This subtopic seeks solutions for on-line aircraft subsystem health monitoring. Solutions should exploit multiple computers communicating over standard networks where applicable. Solutions can be designed to monitor a specific subsystem or a number of systems simultaneously.

Resulting commercial products might be implemented in a distributed decision-making environment such as a virtual flight research center, a disciplinary-specific collaborative laboratory, an onboard diagnostics system, or a maintenance and inspection network of potentially global proportion.
Proposers should discuss who the users of resulting products would be, e.g., research/test/ development; manufacturing; maintenance depots; flight crew; airports; flight operations or mission control; air traffic management; or airlines. Proposers are encouraged to discuss data acquisition, processing, and presentation components in their proposal. Examples of desired solutions targeted by this subtopic include:

- Real-time autonomous sensor validity monitors
- Flight control system or flight path diagnostics for predicting loss of control
- Automated testing and diagnostics of mission-critical avionics
- Structural fatigue, life cycle, static, or dynamic load monitors
- Automated nondestructive evaluation for faulty structural components
- Electrical system monitoring and fire prevention
- Applications that exploit wireless communication technology to reduce costs
- Model-reference or model-updating schemes based on measured data that operate autonomously
- Proactive maintenance schedules for rocket or turbine engines, including engine life-cycle monitors
- Predicting or detecting any equipment malfunction
- Middleware or software toolkits to lower the cost of developing on-line health-monitoring applications
- Innovative solutions for harvesting, managing, archival, and retrieval of aerospace vehicle health data

A1.04 Aircraft Icing Systems
Lead Center: GRC
Participating Center(s): None

A major goal of the NASA Aircraft Icing Program is to increase the level of safety for all aircraft flying in the atmospheric icing environment. To maximize the level of safety, aircraft must be capable of handling all possible icing conditions by either avoiding or tolerating the conditions. Proposals are invited that lead to innovative new approaches or significant improvements in existing technologies for inflight icing condition avoidance (icing weather information systems) or tolerance (aircraft icing protection systems and design tools). Of particular interest are technologies that are compatible with emerging aircraft designs (i.e., sensitive electronic systems, digital flight decks, and advanced wing designs). Onboard systems must be aerodynamically non-intrusive , practical, and must consider weight, power, size, and cost for successful integration into aircraft. To receive consideration for funding, all proposals submitted under this subtopic must demonstrate significant advantages over existing technologies. The areas of greatest interest are:

- New practical, inflight and/or ground-based, real-time remote sensing technologies for the measurement of the supercooled water droplet and temperature environment. The technology must be capable of quantifying the environment to allow for the prediction of the severity of airframe icing, and to identify potential avoidance and escape routes, and must have practical range (at least 20 km) and cloud penetration capability. The scanning

update cycle rate needs to be on the order of 1 minute to account for rapid changes in the icing environment. Remote measurement systems must be capable of quantifying liquid water in both pure liquid clouds and those with ice crystals.
- Dual or multi-band radar analysis techniques that can function in the Mie scattering regime for the remote measurement of icing conditions.
- Radome technology for microwave wavelength radar and radiometers that remains completely clear of liquid water in all weather situations.
- In situ icing environment measurement systems that can provide practical, very low cost validation data for emerging icing weather information systems and atmospheric modeling. Measured information must include location, altitude, cloud liquid water content, temperature, and ideally cloud particle sizing and phase information. Possible solutions include multiple aircraft sampling and radiosonde based systems.
- Low power and low cost anti-icing systems, including technologies that protect composite structures. A system must be capable of operating under all potential environmental conditions and should be capable of operating automatically or with minimal cockpit crew interaction.
- Practical analysis tools for the integrated design and optimization of hot gas ice protection systems. The tool must model the entire heat path from source to protected surface, including the conduction path through the surface and the water loading on the external surface.

A1.05 Non-destructive Evaluation and Health Monitoring of Structures and Materials
Lead Center: LaRC
Participating Center(s): ARC

Innovative and commercially viable technologies are being solicited for the development of non-destructive evaluation (NDE) and health-monitoring sensors and instrumentation. Concepts in computational models for signal processing and data interpretation to establish quantitative characterization and event determination are also of interest. Evaluation technologies may incorporate ultrasonics, laser ultrasonics, optics and fiber optics, shearography, video optics and metrology, thermography, electromagnetics, acoustic emission, X-ray, management of digital NDE data, biomimetic, and nano-scale sensing approaches for structural health monitoring. There is additional specific interest in non-contacting, remote, rapid, and less geometry sensitive technologies that reduce acquisition costs or improve system sensitivity, stability, and operational costs. Advancements in integrated multi-functional sensor systems, autonomous inspection approaches, distributed/embedded sensors, roaming inspectors, and shape adaptive sensors are also specifically sought.

Technologies may be applied to:
- Adhesives, sealants, bearings, coatings, glasses, alloys, laminates, monolithics, material blends, and weldments
- Thermal protection systems
- Complex composite and hybrid structural systems
- Low density and high temperature materials

Technologies may be used for:
- Characterizing material properties
- Assessing effects of defects in materials and structures
- Evaluation of mass-loss in materials
- Detecting cracks, porosity, foreign material, inclusions, corrosion, disbonds
- Detecting cracks under bolts
- Real time and in situ monitoring, reporting, and accumulated damage characterization for structural durability and life prediction/determination
- Repair certification
- Environmental sensing
- Electronic system/wiring integrity assessment
- Characterization of load environment on a variety of structural materials and geometries including thermal protection systems and bonded configurations
- Identification of loads exceeding design
- Monitoring loads for fatigue and preventing overloads

- Suppression of acoustic loads
- Early detection of damage
- In situ monitoring and control of materials processing

The anticipated structural applications to be considered for NDE and health monitoring development include a variety of high stress and hostile aero-thermo-chemical service environments projected for aerospace systems.

A2 Aviation System Capacity and Productivity

A major NASA goal in global civil aviation is to triple the aviation system throughput in all weather conditions while maintaining safety. An additional goal is to significantly reduce the cost of air travel. These increases in the capacity and productivity of the National Airspace System (NAS) can be achieved through development of revolutionary ground-based and airborne operations systems, new vehicle technologies and utilization of advanced computational approaches and information technology methodologies for aerospace system development.

A2.01 21st Century Air-Traffic Management
Lead Center: ARC
Participating Center(s): None

Innovations in Air-Traffic Management (ATM) are required to make current systems more efficient as well as improve the next generation National Airspace System (NAS). The challenge for the next generation ATM system is to accommodate growth in air traffic while reducing the aircraft accident rate by a factor of five within 10 years from 1997, and by a factor of ten within 20 years. This can only be achieved by the development of decision support tools for controllers, pilots and airline operations, and by the introduction of technical innovations in communication, navigation, and surveillance (CNS). It requires a new look at the way airspace is managed and the automation of some crew functions, thereby intensifying the need for a careful integration of machine and human performance. In addition, advances in technologies such as Differential GPS (DGPS) and Automatic Dependent Surveillance-Broadcasting (ADS-B) are revolutionizing aerospace operations. These and other advanced technologies will advance the development of Runway Independent Aircraft that do not require conventional runways, as well as, improve operations at existing airport infrastructures. These technologies show promise in enhancing the efficiency and safety of airport traffic management. Innovative and economically attractive approaches are sought to advance technologies in the following areas:

- Decision support tools (DST) to assist pilots, controllers and dispatchers in all parts of the airspace (en route, terminal and surface)
- Integration of DST across different airspace. Simulation and modeling tools to assess benefits of new concepts technologies and concepts leading to greater airborne operational independence
- Methods of integrating air and ground roles and responsibilities
- Distributed decision-making and its impact on the stability of the airspace
- System robustness and safety: sensor failure, threat mitigation, health monitoring
- Weather modeling and improved trajectory estimation for traffic management applications
- New concepts in air space management and impact of Commercial Space Transportation on ATM
- Role of data exchange and data link in co-operative decision-making
- Modeling of the National Airspace System
- Human factors and workload concepts relating to safe control/integration of aircraft and other ground vehicles systems
- Distributed complex, real-time simulations
- Environmentally friendly ATM and aircraft operations
- Automation concepts for advanced ATM systems
- Intelligent software architecture
- Technologies and innovative methods to integrate simultaneous movement of the ground vehicles and the aircraft fleet

- Operational products for Simultaneous Non-Interfering (SNI) approaches, departure and runway traffic
- Intermodal Transportation technologies

A2.02 Flight Technologies for Improved Aviation System Capacity
Lead Center: ARC
Participating Center(s): None

To achieve the NASA objective of tripling the aviation system capacity within 25 years, revolutionary changes to the current civil operational environment are envisioned. These changes include new and improved vehicle technologies to fully accomplish this objective. Runway-Independent Aircraft with a vertical or extremely-short takeoff and landing (ESTOL) flight capability will enable the mobility required to achieve door-to-door delivery of people, goods, and services within this new air transportation system. These vehicles must meet civil global aviation requirements for safer, quieter, more efficient, and affordable aircraft. These requirements directly influence the Aerospace Technology objectives identified by NASA to support the Agency's mission.

Many aspects of the aeromechanics and flight control of rotorcraft and powered-lift aircraft are not thoroughly understood or predictable enough to enable efficient and accurate design processes for economically-viable civil aircraft with a vertical flight capability. NASA requires innovative methods, approaches, and technologies that describe phenomena involved in rotorcraft and powered-lift aerodynamics, dynamics, acoustics and autonomous control; provide greater knowledge of the detailed characteristics of these phenomena; and permit well-verified designs. Innovative developments with applications to advanced tilt rotors, revolutionary powered-lift aircraft, a spectrum of helicopter configurations, personal vertical flight transportation vehicles, and hover-capable unmanned aerial vehicles of all sizes are needed to refine the next generation of civil aircraft that will meet civil global aviation requirements for safer, quieter, more efficient, and lower direct operating cost aircraft. These requirements directly impact the Research and Technology Programs identified by NASA to support the agency's objective of increased aviation system capacity as well as improved mobility, reduced noise, increased safety, and innovation in technology and engineering.

Examples of research topics currently of importance include: efficient design tools which reduce design cycle time; improved vehicle performance with reduction in ownership and operation costs; advanced active control strategies/methodologies for aeromechanics, flight control, and enhanced vehicle capability; innovative solutions for reduction of airframe vibration, vibratory loads, and radiated noise; and technologies for improved safety. Adaptation of emerging technologies such as biologically-inspired engineering, information technology, and nanotechnologies is also encouraged. New analysis methodologies addressing the unique aspects of civil rotorcraft and powered-lift aircraft through CFD/CSM/CAA for individual and integrated vehicle systems are also sought.

A2.03 Intelligent Aerospace Systems Management
Lead Center: ARC
Participating Center(s): GRC

With the dramatic increase in computational capability and information technology, several alternative approaches to traditional vehicular guidance, navigation, and control have been offered. These approaches include neural networks, annealing algorithms, biomimetics, and fuzzy logic. Many of these approaches have had specific applications in the aerospace industry, but less so than in other commercial industries. Safety is often cited as a contributing factor for this difference; however, that citation is becoming less defensible with the promulgation of these ideas into vehicles outside the aerospace domain.

The objective of this subtopic is to both bolster and foster collaboration between the aerospace environs and these recent computational and informational approaches. Airborne vehicles of all types will be considered; however, emphasis on hovering and extremely short takeoff and landing powered-lift vehicles, both manned and unmanned, will be given. Technology innovations sought include:

Unmanned aerial vehicle guidance and control
- Intelligent guidance for single or coordinated groups of vehicles with constraints
- Use of genetic, simulated annealing, tabu search, or great deluge algorithms
- Real-time optimal trajectory generation for aggressive maneuvering

- Interactions between autonomous control and operator control
- Fault tolerant methods (tradeoffs of parallel versus analytical redundancy)

Flight control and integrated flight propulsion control
- Stability and performance sensitivities for practical neural networks or fuzzy logic applications
- Hybrid systems analysis
- Biomimetic applications

Helicopter flight control
- Interactions between on-blade control for vibration and handling qualities
- Rotor state feedback applications
- Sensing and estimation tradeoffs of using rotor states versus using rigid mode lead filtering
- Integrated flight and propulsion control with rotor RPM

Open architecture information sharing
- Platform independent, wireless flight test applications
- Self-contained, wireless, airborne information devices with head mounted displays

A3 Environmental Compatibility: Noise and Emissions

NASA has very aggressive goals for providing technologies that will ensure the noise and emissions environmental compatibility of future commercial aircraft. In particular, the noise goals are to reduce the perceived noise levels of future aircraft by a factor of two (10 EPNdB) within 10 years of 1997, and a factor of four (20 EPNdB) within 20 years. The emissions goals are to reduce aircraft emissions by a factor of three within 10 years and a factor of five within 20 years. These goals are necessary to meet increasingly stringent local, national, and international noise and emission regulations while enhancing operating safety and productivity and increasing aviation system throughput. Accomplishment of these goals will require revolutionary airframe and propulsion technologies to be developed and handed off to the aerospace community in a timely fashion. Particular areas of interest are: (1) Noise prediction and reduction technologies for propulsion source noise, nacelle aeroacoustics, airframe noise, and noise minimal flight procedures for future subsonic and supersonic commercial aircraft. (2) Aircraft interior noise reduction technologies to improve passenger and crew comfort. (3) Emissions reduction technologies for ultra low NOx emissions combustor concepts which also reduce the aerosol and particulates emissions. (4) Innovative airframe and propulsion concepts relative to these goals.

A3.01 Airframe Systems Noise Prediction and Reduction
Lead Center: LaRC
Participating Center(s): None

Innovative technologies and techniques are necessary for the introduction of efficient, environmentally acceptable airplanes, rotorcraft and advanced aerospace vehicles. Improvements in noise prediction and control technologies are needed for jet, propeller, rotor, fan, turbomachinery, and airframe noise sources to reduce the impact on community residents, aircraft passengers and crew, and launch vehicle payloads. Innovations in technologies and algorithms for the following specific areas are solicited:

- Fundamental and applied computational fluid-dynamics techniques for aeroacoustic analysis, particularly for use early in the design process.
- Simulation and prediction of aeroacoustic noise sources particularly for airframe noise sources and situations with significant interactions between airframe and propulsion systems.
- Innovative active and passive acoustic treatment concepts for engine nacelle liners.
- Technologies for active and passive control of aeroacoustic noise sources for Blended Wing Body and other advanced aircraft.
- Reduction technologies and prediction methods for rotorcraft and advanced propeller aerodynamic noise.

- Computational and analytical structural acoustics techniques for aircraft and advanced aerospace vehicle interior noise prediction, particularly for use early in the airframe design process.
- Technologies and techniques for active and passive interior noise control for aircraft and advanced aerospace vehicle structures.
- Prediction and control of high-amplitude aeroacoustic loads on advanced aerospace structures and the resulting dynamic response and fatigue.
- Development and application of flight procedures for reducing community noise impact of rotorcraft and future subsonic and supersonic commercial aircraft while maintaining safety, capacity and fuel efficiency.

A3.02 Propulsion System Emissions and Noise Prediction and Reduction
Lead Center: GRC
Participating Center(s): None

Emissions: Current environmental concerns with subsonic and supersonic aircraft center around global warming and the impact on the Earth's climate and, if not addressed, may threaten future market growth. Carbon dioxide (CO2) and oxides of nitrogen (NOx) are the major emittants of concern coming from commercial aircraft engines. CO2 is a greenhouse gas which may impact the warming of the Earth's climate. NOx emissions can destroy ozone in the upper atmosphere which protects humans from harmful uv radiation from the Sun and NOx can produce ozone in the lower atmosphere. Around airports, it appears as smog and causes breathing and health problems. Current state-of-the-art engines and combustors in most subsonic aircraft are fuel efficient and meet the 1996 ICAO NOx limits. The Kyoto Agreement is applying pressure for additional CO2 reductions, and Europe and the U.S. Environmental Protection Agency are applying pressure for additional NOx reductions at takeoff and possibly cruise conditions. Stringent CO2 and NOx limits could result in emissions' fees or limited access to some countries. Also, recent observations of aircraft exhaust contrails (from both subsonic and supersonic flights) have resulted in growing concern over aerosol, particulate, and sulfur levels in the fuel. In particular, aerosols and particulates from aircraft are suspected of producing high altitude clouds which could adversely affect the Earth's climatology. NASA has set some very aggressive goals for reducing emissions of future aircraft by a factor of three within 10 years and by a factor of five within 20 years. Advanced concepts research for reducing CO2 and NOx, and analytical and experimental research in characterization (intrusive and non-intrusive) and control (through component design, controls, and/or fuel additives) of gaseous, liquid and particulates of aircraft exhaust emissions is sought. Specific aircraft operating conditions of interest include the landing-takeoff cycle as well as the in-flight portion of the mission. Areas of particular interest are:

- New concepts for reducing carbon dioxide, oxides of nitrogen (NO, NO2, NOx), unburned hydrocarbons; carbon monoxide, particulate, and aerosols emittants (novel propulsion concepts, injector designs to improve fuel mixing, catalysts, additives, etc.);
- New fuels for commercial aircraft which minimize carbon dioxide emissions;
- Innovative active control concepts for emission minimization with an integrated systems focus including emission modeling for control, sensing and actuation requirements, control logic development, and experimental validation are of interest; and
- New instrumentation techniques are needed for the measurement of engine emissions such as NOx, SOx, HOx, atomic oxygen and hydrocarbons in combustion facilities and engines. Size, size distributions, reactivity, and constituents of aerosols and particulates are needed, as are temperature, pressure, density, and velocity measurements. Optical techniques that provide 2-D and 3-D data; time history measurements; and thin film, fiber optic, and MEMS-based sensors are of interest.

Noise: NASA intends to provide enabling technologies to reduce the perceived noise levels of future aircraft by a factor of two (10 EPNdB) from 1997 technology aircraft by 2007, and a factor of four (20 EPNdB) by 2022. These goals are necessary to meet increasingly stringent local, national and international community noise regulations while enhancing operating safety and productivity and increasing aviation system throughput. Engine noise reduction technologies are required in the areas of propulsion source noise, nacelle aeroacoustics, and engine/airframe integration. These aggressive aircraft noise reduction goals will require revolutionary advances in propulsion technologies. Some of the key technologies needed to achieve these goals are revolutionary propulsion systems for reduced noise without significant increases in cost and emissions. Noise reduction concepts need to be identified that provide economical alternatives to conventional propulsion systems. NASA is soliciting proposals in one or more of the following areas for Propulsion System Noise Reduction:

- Innovative acoustic source identification techniques for turbomachinery noise. The technique shall be described and demonstrated on a relevant source. A simple source may be used where the solution is known to demonstrate the technique. A clear explanation on how the technique can be applied to turbofan engines should be included. The technique should be capable of identifying sources contributing to dominant engine components, such as fan and jet noise. Fan Noise: The technique shall be capable of separating fan sources such as fan-alone versus fan/stator interaction for both tones and broadband noise. Sufficient resolution is needed to determine the location of the dominant sources on the aerodynamic surfaces. Jet Noise: The technique shall be capable of locating both internal and external mixing noise for dual-flow nozzles found in modern turbofans.
- Innovative turbofan source reduction techniques. Methods shall emphasize noise reduction methods for fan, jet and core components without compromising performance for turbofan engines. A resulting engine system that incorporates one or more of the proposed methods should be capable of reducing perceived noise levels anywhere from 10 to 20 EPNdB relative to FAR 36, Stage 3 certification levels.

Advanced Materials for Reduced Emissions: Proposals are also sought to address advanced materials, their development, and their application to primary propulsion systems such as aircraft gas turbines, rocket and turbine based combined cycle engines, and rocket engines as well as auxiliary power sources in aircraft and space vehicles. Materials of interest include any especially used in propulsion systems such as high temperature polymers, nickel base alloys, ceramic matrix composites, coatings for these, and processes for their economical and reliable preparation.

A4 Small Aircraft Transportation System

Numerous factors combine to create opportunities for a small aircraft transportation system for business and personal travel in the 21st century. These include a rapid growth in the use of air travel (creating safety and affordability issues and increasing pressure on National Airspace System (NAS) capacity for operations by the Government and private sector users), declining numbers of communities served by scheduled air carriers, increasingly stringent international environmental standards, an aging fleet of small aircraft, and aggressive foreign competition. NASA seeks innovative technologies supporting advances in flight systems, airspace and ground systems infrastructure, integrated design and manufacturing and aircraft configuration design concepts as well as general aviation propulsion technologies.

A4.01 Small Aircraft Transportation System Technologies
Lead Center: LaRC
Participating Center(s): None

NASA seeks innovative technologies to support advances for small aircraft transportation systems that substantially increase the demand for retrofit of existing aircraft, new aircraft and airport and airspace utilization. Of specific interest are advanced, affordable, certifiable technologies for human-factors engineered display of flight information for total situational awareness and simplified integration of flight controls with displays and propulsion systems. In addition, innovations are desired in cost-effective, user-friendly improvements in the graphical display of weather, traffic, and NAS facilities' information services in the cockpit. NASA also seeks innovations in manufacturing methods and materials that can radically reduce the unit cost of small aircraft. Specifically, proposals are sought for the following areas:

Aircraft Configuration

- Advanced concepts that reduce the landing speed for FAR Part 23 aircraft under 6,000 pounds by half. Advanced concepts for roadable aircraft are also desired. This category must include a sound business plan for production with a technical plan providing for compatibility with the emerging National Airspace System architecture and a certification plan to meet at least one of the following applicable FARs: Part 103 (Ultra-lite vehicle), Part 21.24 (Primary Category Aircraft), Part 23 (Certified Aircraft) or Part 27 (Rotorcraft), or Part 21.191 Advisory Circular AC No: 20-27 series (Experimental Homebuilt Aircraft).

Flight System Technologies, Information Systems and Pilot Vehicle Interface

- Cost-effective advances in emerging navigation and graphical weather displays, graphical depiction methods, intuitive cockpit display systems with emphasis on pilot-display interface, flight controls, voice interface, portable and wearable display technologies, communications and human factors engineering technologies to aid pilot decision-making and to reduce cockpit workload.

Certifiable Off-the-Shelf System Hardware and Software

- Affordable cockpit systems including sensors, attitude-heading reference systems, terrain, obstacle, and hazardous weather avoidance systems, and applications for standardized data bus system architectures such as firmware, software, design and maintenance tools, and flight information and management products for airplane systems status and flight planning.

Airspace Infrastructure

- Advances and innovations in digital high-speed, high-bandwidth communications, and intelligent system design for automated, collaborative decision making, and systems for collision avoidance.

Integrated Design and Manufacturing

- Innovative manufacturing methods and materials providing significant advances in the cost, safety, weight, and cabin comfort for general aviation aircraft through materials technology, structural designs and assembly, and crash-worthiness. All proposals should include supportability plans (support infrastructure, maintenance requirements, operations, and training), certification plans (cite specific FARs), compatibility with current and future airspace architecture, and a clear path to commercialization.

A4.02 Small Aircraft Transportation System Propulsion Technologies
Lead Center: GRC
Participating Center(s): None

NASA seeks proposals that offer small aircraft dramatic improvements in acquisition and life-cycle costs, performance, safety and reliability, environmental compatibility (noise, emissions and fuel), ease of operation and passenger comfort through innovative propulsion concepts and/or integration of innovative propulsion technologies. In all cases, the offeror must demonstrate acquisition and life-cycle costs that are at least comparable to current propulsion system costs. Anticipated benefits must be defined using appropriate theoretical and experimental data. An understanding of the basis of the technology innovation and its application to aircraft engines must be demonstrated. Offerors must address commercialization potential. Paths to FAA certification must be described. Proposals are sought in the following areas:

Propulsion Technologies

NASA seeks propulsion technologies for small aircraft that will result in substantial improvements over those targeted in the NASA General Aviation Propulsion program. Any improvements in areas such as performance, safety, and environmental compatibility must be accomplished with affordability as a prime consideration. Substantially reduced costs, at least 75 percent less than 1997 systems, are highly preferred. Advanced technologies which could lead to advantageous alternate propulsion systems and fuels (e.g., electric propulsion, hydrogen fuel, etc.) are also sought. Offeror must provide strong rationale for the viability and affordability of the propulsion concept which would use the proposed technology, and show substantial benefits over conventional propulsion systems. It is recognized that unconventional propulsion systems will likely be long term developments, however, it is highly preferred that the specified technology development addressed by the offeror have an application which could be commercialized in the nearer term.

Propulsion System Control and Health Monitoring Technology

NASA seeks proposals for low cost electronic engine control and health monitoring system technologies which substantially reduce pilot workload, fuel consumption, and engine emissions, and increase safety, reliability, and time between overhaul (TBO). Engine diagnostics should focus on pilot notification of engine status and operability, post-flight diagnostic methods, trend analysis, maintenance aides, and automatic fault accommodation. Much of this technology already exists, but it is too costly and/or too costly to certify for light aircraft. In some cases, cost reductions by orders of magnitude must be achieved. Development of methods for using commercially available high volume hardware and achieving low cost software production and validation is encouraged.

A5 Access to Space

Of paramount importance is the increase in safety and reliability of our space transportation systems and our goal is to increase flight safety by two orders of magnitude within 10 years from 1997 and by four orders of magnitude in 25 years. Goals also include reducing the payload cost to low earth orbit by an order of magnitude, from $10K to $1K per pound, within 10 years from 1997 and from $1K to $100's per pound by 2025.

A5.01 Advanced Space Transportation System Technologies
Lead Center: MSFC
Participating Center(s): ARC

Second and third generation reusable launch vehicle (RLV) systems will require high propellant mass fraction, high thrust to weight propulsion, reliable system performance, extended reusability, autonomous operation, and efficient pre-mission planning in order to achieve cost and crew safety goals. This subtopic emphasizes innovative hardware concepts, subsystems, and design and analysis tools to support development of next generation launch vehicles while lowering operations cost and improving crew safety. Methodology, design and analysis tools, and hardware developed under this subtopic should address technical issues related to propellant tanks, propulsion subsystems, thermal control subsystems, thermal protection systems, structures, guidance, navigation, and control (GN&C), fluid dynamics, supporting discipline analysis, and launch vehicle systems integration issues. Specific areas of interest for technology advancement and innovation include the following:

- Low-cost, lightweight design concepts for propellant tanks and vehicle structures to lower overall vehicle structural mass fraction.
- Control and health management of vehicle and propulsion structural systems by using sensors and effectors that have little influence on the structural system parameters with the exception of the structural damping parameters. This also includes real time health monitoring and control of propulsion systems, reliable lightweight sensors, real time data handling techniques, and associated recognition software.
- Systems to provide continuous estimation of center of mass and inertial properties along with real-time tuning of control algorithms to reflect known changes in vehicle response or sensor performance, and accurate, continuous estimation of fuel remaining on board.
- Advanced concepts and techniques to meet thermal control requirements of various launch vehicle subsystems and payload thermal requirements.
- Innovative thermal protection system concepts such as advanced microencapsulated phase change materials to support RLV thermal protection system coating applications, instrumentation analysis tools, and testing techniques applicable to RLVs, cryo-tanks, and vehicle base heat shield regions.
- Innovative vehicle preliminary design tools that support the design, analysis, and integration of vehicle subsystems and propulsions systems into the vehicle (such as the ability to assess operability of the overall launch vehicle concept and to model the impacts of design changes on vehicle cost, operations, crew safety, vehicle aerodynamics, and controllability). These tools would significantly enhance the overall systems engineering evaluation of potential RLV concepts.
- Integrated CAD, solid-model, structural, dynamic, thermal, and fluid-flow, analysis methods for multidisciplinary analysis and optimization of subsystems, components, and overall launch vehicles; and improved vehicle analysis tools in the areas of stress, thermal, structural, fluid dynamics, and acoustics.
- Manufacturing and testing techniques that will allow for significant reduction in the cost and schedule required to perform wind tunnel aerodynamic testing of candidate RLV configurations.
- Automated propellant management systems; and technologies and innovative engineering capabilities to produce propulsion storage, feed, pressurization, fill and drain, vent, and support/restraint systems that are robust, lighter, or require less volume.
- Optimal fault detection and redundancy management strategies; execution software and advanced navigation hardware/software architectures; and adaptive GN&C utilizing data from sensors such as GPS.
- Advanced guidance concepts that will reduce operational costs and increase reliability by autonomously reshaping trajectories and retargeting landing sites in the presence of abort/failure situations to satisfy vehicle and control constraints and to achieve a safe abort.

- Advanced control concepts that will reduce operational costs and increase reliability by adapting to changing missions/payloads/vehicle models/failures and abort scenarios without requiring ground effort for retuning and analysis.
- Automated mission planning techniques for planning flight operations of RLVs, including trajectory planning, launch window and timeline determination, generation of initialization loads, and verification that the GN&C will successfully fly the vehicle.
- Analysis and testing techniques for prediction and measurement of damage and stress including life prediction, progressive internal damage and dynamic response in structures containing ceramic-matrix, metal-matrix composites, or other composite materials; and nondestructive evaluation of structural integrity of vehicle subsystem and component materials. Methods for efficient characterization of frequency response functions of large structures, and analysis and testing techniques for passive and active vibration isolation devices for launch vehicles and payloads.
- Advanced methods and tools for prediction of dynamic and unsteady environments applicable to RLV systems and components. Methods to predict and evaluate the internal fluctuating environments of propellant delivery systems, dynamic contribution of cavitating pumps, and vehicle/engine system dynamic stability. Methods to predict and evaluate steady and unsteady external environments of complex vehicle/engine combinations related to geometrically complex external aerodynamics, engine start/launch overpressures, and flow dynamics noise.
- Advanced technologies for integrated structural systems such as integrated thermal and structural cryogenic tanks, efficient and effective repair techniques, technologies for modal, acoustic and static testing of large-scale aerospace structural systems, experimental-empirical methods for composite material thermal characterization and response prediction.
- Advanced airbreathing/rocket based combined cycle engine concepts or other combined cycle concepts. Technologies critical to the implementation of such concepts, such as liquid air production or detonation physics, are also of interest. These advanced cycle concepts should have a clear advantage over existing all rocket propulsion systems.

A5.02 Reusable Launch Vehicle Airframe Technologies
Lead Center: LaRC
Participating Center(s): MSFC

Next generation space transportation systems must address the significant challenge of significantly reducing the cost of space access while providing orders-of-magnitude improvements in safety. To accomplish these goals, the airframes/spaceframes for future launch vehicles and upper stages must be reusable and incorporate advanced technologies in materials and structural concepts, validated, safe structural analysis and design technologies, and improved manufacture of large-scale, advanced structures; and must utilize advanced control, health monitoring, and maintenance technologies to enable low cost and safe operations. To facilitate the improvement of safety, the uncertainties in airframe loads, responses and failure mechanisms must also be reduced so that design margins that contribute to safety can be quantified with an accuracy much greater than is possible today. The conflicting requirements of low cost and safety must also be balanced with the need for performance sufficient for space transportation vehicles.

Airframe systems of primary interest in this subtopic include innovative concepts in reusable cryogenic propellant tanks, and "integrated thermal structures" (i.e., airframe structures, such as integral cryogenic tanks, intertanks, wings/fins, thrust structures, fairings, control surfaces and leading edges that are hot structures or have the reentry thermal protection system closely integrated with the structure). Proposals for innovative research in design and mechanics, and in materials technologies addressing these airframe systems are solicited. Proposals of specific interest in this subtopic include one or more of the following items:

Design and Mechanics

- Specialized modeling, analysis, and design tools for integrated structural, thermal, thermal-structural, or acoustic responses, and innovative measurement and test methods for design validation. Application of methodology to circular and multi-lobed, membrane cryogenic tanks, and for conformal, non-membrane tanks is of special interest.

- Novel methods for prediction and testing of material and structural durability and damage tolerance with emphasis on cryogen leakage, environmental degradation, combined thermal-mechanical loads, and operation beyond nominal design conditions; and related methods to repair damaged structures.

Materials Technologies

- Significant advances in critical properties for high-temperature nickel, iron, and titanium alloys, intermetallics, refractory metals, Polymer Matrix Composites (PMCs), Ceramic Matrix Composites (CMCs), Metals and Metal Matrix Composites (MMCs) along with their related processing into useful product forms for fabrication into the airframe systems of interest.
- Materials technologies focused on advanced, high temperature materials compatible with cryogenic and gaseous hydrogen and oxygen; and for composite tanks, focused on cryogen leakage prevention and/or detection and/or sealing.
- Practical processing methods for large-scale manufacture of cryogenic tanks with efficient and reliable joining, and process development for advanced forming such as out-of-autoclave manufacture for composites, and near-net-shape and free-form fabrication for metals.

A5.03 Space Transportation System Manufacturing Technologies
Lead Center: MSFC
Participating Center(s): None

Innovative manufacturing, materials, and processes technologies are sought for increasing safety and reducing cost and weight of space transportation propulsion, launch vehicle, and spacecraft systems and components. NASA is seeking research proposals in four major areas: Polymer Matrix Composites (PMCs), Ceramic Matrix Composites (CMCs), Metals and Metal Matrix Composites (MMCs), and Intelligent Synthesis Environment (ISE) for manufacturing. However, functionally formed components are also of interest (e.g., composed of a CMC and PMC, high to low thermal conductivity materials, etc.). As appropriate, proposals should justify selection of material constituents for process development, provide flexible, process development matrix correlated to test matrices, verify processes with microscopic analysis (e.g., microprobe, SEM, XRD, etc.) and macroscopic analysis (e.g., tensile strength, interlaminar shear strength, thermal and physical properties, etc.), explain how aspects of similar, previous efforts are leveraged, verify specific end-use application by testing for permeability, thermal shock, etc., and explain key issues and how mitigated. For those efforts that fabricate components, plans are sought which describe how the component will handle the potential system requirements (e.g., how components/structures are joined, manifolded, integrally and specifically function, etc.) and describe component/coupon nondestructive evaluation plans. Also, any plans necessary for manufacturing scale-up for target components should be described and deliverables listed. Deliverables that are sought include: Components/systems, test data (component, stress-strain curves, shear, etc.), material analyses (microscopic analysis, etc.), and coupon samples for testing and analysis as appropriate. Proposers should strive to develop processes that ensure worker saftey and health.

PMCs: Advancement in the following areas to promote the utilization of advanced polymer matrix composite materials in structures, components, and systems include, but are not limited to: Large scale manufacturing, non-autoclave curing, especially automated fabrication, techniques using e-beam, thermoplastics, or other in situ technologies for providing damage tolerant and repairable structures, development of materials and manufacturing processes compatible with Fuels/Oxidizers, and technologies for bonding PMCs.

CMCs: CMCs composed of fibers selected by end users such as high strength carbon fibers, SiC fibers, etc. are desired. Advanced fiber interface coatings yielding optimal composite life and composite performance with respect to cost and time for fabrication are also desired. The following areas for CMCs are of interest, but not limited to: pressure containment vessels (e.g., lining for turbopump housings, tanks, and integral injector and thrust chambers-with/without active cooling), cooled panels, inter-engine seals for CMC nozzles, inserted blades for turbine disks, and process and component operation health monitoring preforms, and low cost (with metrics) rapid, scalable, repeatable fabrication processes.

Metals and MMCs: Advanced low-cost manufacturing processes such as pressure infiltration casting, laser engineered near net shaping, and electron beam physical vapor deposition are desired. These processes and joining techniques for manufacturing metallic or metal matrix composite (MMC) propulsion system components should target increasing specific strength, specific stiffness, and temperature and oxidizing or high pressure hydrogen environments. Develop and optimize metallic matrix alloy compositions for MMCs with unique properties such as high specific strength, high ductility and good joinability (welding/brazing). The following aspects are to be considered: Alloy type (aluminum, Copper, Haynes 214, Mg, nanophase alloys), reinforcement material (Al_2O_3, SiC, B_4C), reinforcement type (particulate, fiber, hybrid, functionally graded). Advanced joining of metallic and MMC materials is also sought for the previously mentioned areas, in addition to bonding and joining of similar and dissimilar materials.

ISE: Developments in ISE and collaborative engineering tools for manufacturing are solicited. Emphasis is placed on: "The Manufacturing Element" of life cycle product development including virtual product development, information-based systems, web-based manufacturing, biomimetic or self-assembly processes, virtual product development and manufacturing simulation, science-based manufacturing, in addition to process control and instrumentation for characterization and verification of material properties (including thermal, optical, electrical, mechanical, and moisture absorption).

A5.04 Space Propulsion Systems Test Operations
Lead Center: SSC
Participating Center(s): None

Proposals are solicited for innovative concepts in the area of propulsion test operations. Proposal should support the reduction of overall propulsion test operations costs (recurring costs) and/or increase reliability and performance of ground test facilities and operations methodologies. Specific areas of interest in this subtopic include the following:

Improvements in Ground Test Operations, Safety and Reliability
- New innovative non-intrusive sensors for measuring flow rate, temperature, pressure, rocket plume constituents, effluent gas detection, hydrogen gas and hydrogen fire detection.
- Improved cryogenic propellant conditioning methods.

Facility and Test Article Health Monitoring Technologies
- Intelligent sensor technology: self-diagnosing, self-calibrating, self-installing, sensors as networked devices capable of operating remotely.
- Software environments to implement an Intelligent Health Monitoring and Diagnostics System (IHMDS) that can ensure efficient operation and integrity of every element in a test stand (elements include sensors, assemblies, components, processes, and procedures).
- Network protocol implementations for fast communication and data transfer for use by networked intelligent devices (sensors, controllers, etc.).
- Small wireless communications for remote sensing and control.
- Smart system components (control valves, regulators, and relief valves) that provide real-time closed-loop control, component configuration, automated operation, and component health.
- Cryogenic propellant transfer system operation technologies which include automated propellant transfer, automated propellant-line (liquid hydrogen) purge systems, and automated and/or manual propellant-line quick-disconnect systems.
- Cryogenic storage tank lifetime monitor systems for temperature cycles, stress, acoustics, pressure, and shock.

A6 In-Space Transportation

Opening the space frontier for exploration, science and commerce will require breakthroughs in in-space transportation technologies. Over half of all spacecraft launched have a final destination beyond low Earth orbit and require some sort of in-space transportation system to get them there. Traditional chemical propulsion systems are inadequate to meet the needs of the next generation of space exploration missions. New technologies or innovative applications of existing technologies for in-space transportation that potentially result in increases in safety and reliability, significantly lower costs, reduced trip times and/or increased payload mass fractions are sought. Transportation technologies to meet these goals can generally be divided into two categories: those utilizing high-energy power sources for thrust and those that obtain propulsion through interaction with the natural environment of space or offboard energy. High Energy Electric and Plasma Propulsion systems can include electrostatic and electromagnetic propulsion, thermal propulsion (fission or solar derived), as well as more futuristic systems based on beamed power, fusion, antimatter, nuclear isomers, and other high-energy density technologies. Propellantless Propulsion systems include solar, plasma, and beamed energy sails; electrodynamic and momentum transfer tethers and elevators; aeroassist, aerocapture, and aerogravity techniques. Technologies that are supportive of these advanced transportation technologies at either the system or subsystem level are of interest. Technologies that support both NASA and commercial space needs are of particular interest.

A6.01 High Energy Propulsion Technologies
Lead Center: MSFC
Participating Center(s): GRC

This subtopic focuses on high energy space transportation propulsion technologies, devices, and systems that could dramatically improve space transportation capability, cost, safety, and reliability and could lead to ambitious robotic and human exploration of the solar system and beyond. Proposals are solicited for innovative research related to high energy, high efficiency space propulsion. Technologies that can be applied to high-payoff commercial applications are of particular interest. Proposals should include analyses addressing feasibility and mission suitability, and plans for demonstrating concept feasibility via test/experiment. Areas of interest include:

- Systems, subsystems, and components needed to enable high efficiency (Isp is greater than 2000 s) in-space propulsion systems with overall propulsion system specific power exceeding 200 W/kg at any point in the solar system.
- Fission propulsion systems, components, and technologies that enable high performance. Technologies may include safety and control systems, innovative radiation shielding techniques, light weight waste heat radiation systems, thermal management systems, and other major system components.
- Fissile fuels and materials required to enable high efficiency, high specific power in-space propulsion systems. Fissile fuels and materials required to enable high thrust-to-weight nuclear thermal rockets with a mission-averaged specific impulse exceeding 875s.
- Futuristic propulsion systems based on fusion (non-tritium based), antimatter, or other advanced high energy processes. Technologies may include pulsed and steady-state fusion propulsion concepts or components and hybrid systems.

A6.02 Propellantless Propulsion
Lead Center: MSFC
Participating Center(s): None

This subtopic will focus on technologies supporting innovative and advanced concepts for propellantless propulsion and other revolutionary transportation technologies. The technologies under Propellantless Propulsion include, but are not limited to: gravity assist and aerogravity assist; solar, laser, and microwave sailing; magnetospheric plasma propulsion; electrodynamic and momentum transfer tether propulsion; and aeroassist/aerocapture. Gravity assist propulsion methods utilize momentum exchange between the payload and a planet's heliocentric angular momentum through gravitational interaction. Solar or laser sailing exchanges momentum with photons through optical reflection. Magnetospheric plasma propulsion involves momentum exchange with solar wind ions through electrodynamic interaction. The electrodynamic tether propulsion method exchanges momentum with a planet's rotational angular momentum through electrodynamic interaction with the planetary magnetic field. The aeroassist/aerocapture propulsion method exchanges momentum with a planet's atmosphere through aerodynamic drag. Proposals should provide development of specific innovative technologies or techniques supporting any of these methods. A plan for demonstrating feasibility, noting any test and experiment requirements, is also recommended.

A7 Design and Analysis for Aerospace Vehicles

The Aerospace Technology Enterprise is engaged in developing the tools, techniques, and technologies to revolutionize the design and development processes of the aerospace industry with the goal to reduce the aerospace vehicle development cycle time. Aerospace vehicle systems design of the future will more fully integrate the various aerospace disciplines and require a greater understanding of not only the critical physics of the various disciplines, but also how the physics of the various disciplines play together. Important elements in the next generation design and analyses of aerospace vehicle systems include: enhanced safety, affordability, productivity, and environmental compatibility. Innovative test instrumentation, and flow control and simulation are key areas in this effort. Flight sensors, sensor arrays, and airborne instruments for flight research are also sought.

A7.01 Modeling and Control of Complex Flows Over Aerospace Vehicles and Propulsion Systems
Lead Center: LaRC
Participating Center(s): ARC

This subtopic solicits innovative ideas, concepts, and methodologies for the measurement, prediction, modeling and control of unsteady aerodynamic and aerothermodynamic phenomena that may be encountered by aerospace vehicles. Biologically inspired approaches and/or ideas for flow control are also solicited in this subtopic. Also of interest are advanced measurement systems and ground testing techniques to provide dynamic and global measuring capabilities, higher bandwidth, and improved resolution. Additionally, the subtopic is interested in innovative computational and experimental techniques that account for the complex aerothermodynamic, mixing, and combustion phenomena impacting the design and development of future space transportation vehicles, aero-assist orbital transfer vehicles, planetary entry probes, and hypersonic air-breathing propulsion systems. Unsteady phenomena of interest include active and passive flow control mechanisms; vortical and separated flows; equilibrium and finite-rate chemistry; thermodynamic and transport properties of multi-component mixtures, gaseous radiation, gas-surface interactions, mixing and combustion, shock-wave/boundary-layer interactions; and laminar, transitional, and turbulent reacting and non-reacting flows. Specific areas of interest include:

- Flow-physics modeling and control of transition and/or transitional flows, turbulence, and turbulence-related phenomena such as heat transfer, skin-friction, acoustics, mixing and combustion, with an emphasis on separated flow and the scaling of ground-based experiments to flight Reynolds numbers.
- Control and/or mitigation of separation, vortical flows, and shock wave phenomenon, including their impact on vehicle drag (turbulent skin friction drag, profile drag, drag-due-to-lift, and wave drag).
- Non-conventional numerical methods for solving fluid-flow equations that increase computational efficiency, accuracy, speed, and utility, including construction of new algorithms, improved computer languages, efficient and adaptive grid-algorithm interfacing, and applications of automation techniques with discretization error assessments.
- Innovative techniques for robust and reliable handling and sharing of large CFD and experimental data sets.
- Analytical and/or computational models/algorithms applicable to the optimization of integrated hypersonic propulsion/vehicle systems.
- Innovative and patentable mixing techniques applicable to hypersonic propulsion, with special consideration placed on the stoichiometric fuel regimes.
- Small-scale devices that initiate and sustain fuel (hydrogen and/or hydrocarbon) ignition and flame holding in supersonic combustor environments, at conditions relevant to hypersonic air-breathing propulsion flight trajectories.
- Advanced test techniques and flow diagnostics (including non-intrusive flow diagnostics and surface diagnostics) for developing definitive databases across speed range from subsonic to hypersonic facilities including shock-expansion pulse facilities.
- MEMS and nano technology sensors and interface electronics for flow measurements including flow velocity, pressure, temperature, shear stress, vibration, force, attitude, and/or acceleration.
- A small onboard multichannel intelligent data system and/or a high-speed wireless (optical or radio frequency) data transfer system with 50 megabits-per-second or higher data rate for wind tunnel model applications.
- Optical flow diagnostic technologies capable of resolving velocity, density, temperature, etc., in a global sense to provide planar or volumetric data, or at multiple points within the flow to provide temporally dependent cross correlations at sample rates on the order of 100 kHz.

A7.02 Modeling and Simulation of Aerospace Vehicles in a Flight Test Environment
Lead Center: DFRC
Participating Center(s): None

Safer and more efficient design of advanced aerospace vehicles requires advancement in current predictive design tools. The goal of this subtopic is to develop more efficient software tools for predicting and understanding the response of an airframe under the simultaneous influence of aerodynamics and the control system, in addition to pilot commands. The benefit of this effort will ultimately be increased flight safety (particularly during flight tests), more efficient aerospace vehicles, and an increased understanding of the complex interactions between the vehicle subsystems. This subtopic solicits proposals for novel, multi-disciplinary, linear or nonlinear, dynamic systems simulation techniques. Proposals should address one or more of the objectives listed below:

- Prediction of steady and unsteady pressure and thermal load distributions on the aerospace surfaces, or similar distributions due to propulsive forces, by employing accurate finite element CFD techniques.
- Effective finite element numerical algorithms for multidisciplinary systems response analysis with adaptive three-dimensional grid/mesh generation at selected time steps.
- Effective use of high-performance computing machines, including parallel processors, for integrated systems analysis or pilot-in-the-loop simulators.
- Innovative applications of high-performance computer graphics or virtual reality systems for visualizing the computer model or results.
- Correlation of predictive analyses with test data or model update schemes based on measured information.

A7.03 Flight Sensors, Sensor Arrays and Airborne Instruments for Flight Research
Lead Center: DFRC
Participating Center(s): GRC, LaRC

Real-time measurement techniques are needed to acquire aerodynamic, structural and propulsion system performance characteristics in flight and to safely expand the flight envelope of aerospace vehicles. The scope of this subtopic is the development of sensors, sensor systems, sensor arrays or instrumentation systems for improving the state-of-the art in aircraft ground or flight testing. This includes the development of sensors to enhance aircraft safety by determining atmospheric conditions. The goals are to improve the effectiveness of flight testing by: simplifying and minimizing sensor installation; measuring new parameters; improving the quality of measurements; minimizing the disturbance to the measured parameter from the sensor presence; deriving new information from conventional techniques; or combining sensor suites with embedded processing to add value to output information. This subtopic solicits proposals for improving airborne sensors and sensor-instrumentation systems in subsonic, supersonic and hypersonic flight regimes. These sensors and systems are required to have fast response, low volume, minimal intrusion and high accuracy and reliability, and include wireless technology. Innovative technologies are solicited in the following areas:

Vehicle Environmental Monitoring
- Nonintrusive air data parameters (airspeed, air temperature, ambient and stagnation pressures, Mach number, air density, flow angle, and humidity at air temperatures as low as -20 deg. F).
- Off-surface flow field measurement and/or visualization (laminar, vortical, and separated flow, turbulence) 0 to 50 meters from the aircraft.
- Boundary layer flow field, surface pressure distribution, acoustics or skin friction measurements or visualization.
- Any of the above measurements in hypersonic flow.

Vehicle Condition Monitoring
- Optical arrays for robust flight control surface position and velocity measurement.
- Sensor arrays for structural load monitoring.
- Robust arrays for engine monitoring and control applications.

Advanced Instrumentation for Aeropropulsion Flight Tests

Thin film and fiber optic sensors, especially those compatible with advanced propulsion system materials such as ceramics and composites, and capable of withstanding the high temperatures and pressures associated with turbomachinery.

- Onboard processing for data condensation, failed sensor identification or other valuable onboard processing capability.

Vehicle Far Field Environmental Monitoring

- Nonintrusive measurements at range of 2-5 kilometers of environmental data (natural and induced flowfields, turbulence, weather, traffic).
- Onboard processing of sensed and telemetered data for integrated storage and strategic presentation to the flight crew.

A8 Revolutionary Concepts in Aeronautics (RevCon)

RevCon, or Revolutionary Concepts in Aeronautics, was conceived to provide NASA's Aerospace Technology Enterprise means to accelerate the exploration of high-risk, breakthrough technologies and enable revolutionary departures from traditional approaches to air vehicle design. The focus of the RevCon is to develop robust flight projects that are responsive to civil, commercial, and Department of Defense (DoD) needs. RevCon focuses solely on aeronautics vehicles and technology. The technology-driven RevCon research may consist of either government-led or industry-led efforts to assure a broad coverage of technologies and applications. Flight research will be focused on technology demonstrations with short development times and must demonstrate high-payoff technologies that significantly advance the state-of-the-art. RevCon projects may include new research vehicles and/or advanced technology experiments on new or existing flight-test platforms. Innovative research partnerships with NASA, utilizing a range of contractual vehicles, are highly encouraged. The intent of soliciting these subtopic elements within the SBIR is to extend potential opportunities to small businesses by providing an incubator type access to future partnering in flight research projects. The RevCon project is an established NASA endeavor which, for successful proposers, may allow opportunities beyond completion of the two-phase SBIR effort. More information concerning RevCon is located at http://www.dfrc.nasa.gov/Projects/revcon/index.html

A8.01 Revolutionary Aerospace Vehicle Systems Concepts
Lead Center: LaRC
Participating Center(s): ARC

The emphasis in this subtopic is on advanced aerospace vehicle concepts for both military and civil applications that accelerate the introduction of high risk, breakthrough technologies in order to enable revolutionary departures from traditional approaches to air vehicle design. These technologies must contribute to improving safety, performance, capacity, reduced emissions and/or noise, and development, production, or operations cost of future air vehicles. The scope includes advanced aerospace vehicle concepts and airframe systems such as wing, fuselage, propulsion/ airframe integration, and technologies applicable to these. Specific technical areas of interest include the following:

- Advanced aerospace vehicle concepts and configurations of subsonic to supersonic air-breathing vehicles and unique propulsion/airframe integration concepts that offer revolutionary increases in performance over conventional aircraft designs.
- Innovative system-oriented research to support, develop, and/or enable advanced airframe technologies and concepts that could impact the design and optimization of any future class of aircraft.
- Efficient, design-oriented application software embodying the mathematical and algorithmic aspects of both multidisciplinary design optimization (MDO) and systems analysis methods for aerospace vehicles.
- Adaptation of newly emerging technologies, such as biomimetics and carbon nanotubes to aerospace vehicle concepts.

A8.02 Revolutionary Technologies and Components for Propulsion Systems
Lead Center: GRC
Participating Center(s): None

NASA seeks highly innovative technologies for propulsion systems and components for advanced high speed aerospace vehicles, to support missions, such as access to space, global cruise, and high-speed transports. The main emphasis in this subtopic is on high-risk, breakthrough technologies in order to revolutionize present-day gas turbine engines to operate over a flight spectrum of up to Mach 8. Specific technical areas include the following:

- Advanced cooling concepts that minimize coolant penalties. This can include innovative cooling systems, materials, fuel cooling of combustor, and endothermic fuels and/or fuel additives to increase the heat-sink capacity or cooling capacity of fuels.
- Innovative technologies relating to combustion process, including fuel injectors, piloting, flame holding techniques for increased performance and decreased emissions, techniques to identify the onset of combustion instability in lean-burn and/or rich-burn, low NOx combustor, ramjet combustion and active and passive combustion controls in order to extend the operability of the combustion components to a wider range of operating conditions.
- New inlet designs to meet functional airflow needs of high Mach number propulsion. For instance, a variable geometry, supersonic, mixed compression inlet. Compatibility with turbomachinery and mode transition across the speed range should be addressed. Special attention should be given to combustor demands along a realistic flight corridor. This flight corridor must be compatible with turbine engine thermal-structure limits.
- New techniques to improve the aerodynamic performance and operability of the inlet, including highly offset subsonic diffusers and designs for boundary layer control, minimizing engine unstart susceptibility, and techniques to identify and control the onset of mode transition between different propulsion concepts within the same internal flowpath or dual flowpaths.
- New controllable and reliable nozzle technologies with optimum expansion efficiency and thrust vectoring capability, including a computational nozzle design methodology to study various geometries and chemistry effects.
- Enabling technologies of components and subsystems that allow turbomachinery to operate at high-speed flight conditions. Specific examples include (1) a lightweight, high pressure ratio compressor which must be protected or removed from the extremely high temperature primary air stream; (2) applications of advanced ceramic/ composite materials or micro-electrical-mechanical systems to enhance the performance and reduce the cost and weight; and (3) innovative inlet flow conditioning.
- New designs for combined/combination cycles, in particular those including turbine propulsion. Alternate engine cycles that meet a unique mission requirement (e.g., global reach, access to space, etc.), including pulse detonation, ramjets, scramjets, and rockets. Proposals can also include development of unique components required for the maturation of alternate propulsion cycles, such as inlets, diffusers, nozzles, air-valves, fuel injectors, combustors, etc.

A8.03 Revolutionary Flight Concepts
Lead Center: DFRC
Participating Center(s): None

This subtopic solicits innovative flight test experiments that demonstrate breakthrough vehicle or system concepts, technologies, and operations in the real flight environment. The emphasis of this subtopic is the feasibility, development, and maturation of advanced flight experiments that demonstrate advanced or revolutionary methodologies, technologies, and concepts. It seeks advanced flight techniques, operations, and experiments that promise significant leaps in vehicle performance, operation, safety, cost, and capability; and require a demonstration in the actual flight environment to fully characterize or validate.

The scope of this subtopic is broad and includes advanced flight experiments that accelerate the understanding and development of advanced technologies and unconventional operational concepts. It is intended to advance and demonstrate revolutionary concepts and is not intended to support evolutionary steps required in normal product development. Proposals should emphasize the need of flight-testing a concept or technology as a necessary means of verifying or proving its worth. The benefit of this effort will ultimately be more efficient aerospace vehicles, increased flight safety (particularly during flight tests), and an increased understanding of the complex interactions between the vehicle or technology concept and the flight environment.

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8.1.2 BIOLOGICAL AND PHYSICAL RESEARCH

NASA's Biological and Physical Research Enterprise conducts basic and applied research to support human exploration of space and to take advantage of the space environment as a laboratory. It creates unique cross-disciplinary research programs, bringing the basic sciences of physics, biology, and chemistry together with a wide range of engineering disciplines. This Enterprise asks questions that are basic to our future: How can human existence expand beyond the home planet to achieve maximum benefits from space? How do fundamental laws of nature shape the evolution of life?

http://SpaceResearch.nasa.gov

B1 Cross-Disciplinary Physical Sciences

The Biological and Physical Research (BPR) Enterprise is taking advantage of the space environment which offers a unique laboratory to study biological, chemical and physical processes. Researchers will take advantage of this environment to conduct experiments in the biological and physical sciences that are impossible on Earth. BPR also seeks to engage the commercial sector in exploiting the economic benefits of the cross-disciplinary physical sciences. In this topic, cross-disciplinary research and enabling technology is sought to understand the effects of gravity on the physical sciences as well as in the area of vibration isolation/measurement technology. This research and technology will provide the basic foundation to integrate our understanding of the role of gravity in the evolution, development and function of living organisms, and in biological and physical processes. BPR is also taking advantage of revolutionary advances in the biomolecular community by conducting basic research to develop breakthrough technologies which will result in prototype biomolecular micro- and nano-systems for the detection, imaging, recognition and monitoring of biological signatures and processes at the molecular level.

B1.01 Exploiting Gravitational Effects for Combustion, Fluids, Synthesis, and Vibration Technology
Lead Center: GRC
Participating Center(s): None

The objective of this research is to deliver new technology in the form of devices, models, and/or instruments of use in microgravity and/or for commercial applications on Earth for:

- Understanding the effects of microgravity on fluid behaviors.
- Self-assembly of colloidal and biomolecular crystals in the fluid phase at nanoscale sizes. The results lay the foundation for understanding phase change, production of novel photonic materials, and fabrication of nanoscale structures.
- Utilizing the mechanics of granular materials to determine how the reduced gravity environment affects transport and mixing of granular solids, with application to in-situ resources utilization (ISRU) and more efficient terrestrial processes.
- Pool and flow boiling systems or subsystems that enable safe, efficient, and reliable heat transfer technologies for thermal control systems application in space.
- Multiphase flow and fluid management to provide designers key information on controlling the location and dynamics of liquid-vapor interfaces in microgravity. This is needed for safe and reliable fluid handling and transport in microgravity.
- Understanding the effects of microgravity on combustion behaviors.
- Measuring the residual accelerations on spacecraft or in ground-based, low-gravity facilities. Emphasis is placed on MEMS or nanoscale devices.
- Novel vibration isolation technology for use in ground-based, low-gravity facilities.
- Improving in-space system performance that relies on fluid or combustion phenomena, principally spacecraft fire safety, especially fire and smoke prevention, detection, and suppression.
- Pollution reduction and improvement of the efficiency of liquid-fueled combustors.

B1.02 Gravitational Effects on Biotechnology and Materials Sciences
Lead Center: MSFC
Participating Center(s): ARC

NASA has interest in experiments that utilize the influence of microgravity on biotechnology processes and materials science to understand physical, chemical, and biological processes. Areas of interest include protein crystal growth and structural analysis techniques, separation science and technology, biomaterials, polymeric materials, advanced electronic and photonic materials, as well as metals and alloys, and glass and ceramic materials technology. Other areas of interest relate to microgravity processing approaches such as containerless processing and advanced thermal processing techniques. Methods for conducting science and technology research required to enable humans to safely and effectively live and work in space are needed. Innovation is sought in the following research areas and in their enabling technologies, including potential commercial applications on Earth:

Biotechnology

- Advancement of high throughput, automated preparation and/or analysis of biological crystals. This may include crystallization robotics, diffraction data collection, and the minimization of crystalline defects.
- Technology designed to help improve our understanding of the effect of gravity on crystallization of biological macromolecules and crystal quality.
- Research and development of technologies and techniques in the field of separations of biological material designed to help improve our understanding of the effect of gravity on separation efficiency.
- Technologies to determine relationships between material substrates, tissue cell culture conditions, and subsequent cell culture development and expression.
- High throughput technologies for the determination of gene expression.
- Biotechnology and instrumentation to help enable safe human exploration beyond Earth orbit for extended periods.

Materials Science

- Novel technologies and materials for efficient radiation shielding during human exploration of space. The materials must be capable of attenuating galactic cosmic rays, solar particles, and secondary particles to acceptable limits.
- Technology and instrumentation leading to high leverage (useful product to Earth-bound weight) materials processes for the utilization in situ of space resources, both materials and energy for application to the establishment of safe, self-sustaining, self-sufficient systems to enable science and a permanent human presence in space and on planetary surfaces.
- Technologies and materials utilizing particles in the nanometer range size, having novel properties with applications to high strength, low-mass materials, advanced electronics, and radiation shielding.
- Innovations in polymers, composites, and other materials that incorporate sensory, effector, and self-repair technologies.
- Technologies imitating nature's ability to self-assemble (bio-mimetic processing). Of particular interest here are applications to functionally graded structures.
- Development of materials for improved sensor technology, leading to the potential for miniaturization and high performance in hostile environments.
- Development of advanced models for the simulation of both liquid and vapor transport that will lead to a better understanding of point defect incorporation into the solid state.
- Advancement of the state-of-the-art for the levitation and containerless processing of molten liquid materials including the development of techniques for uniform heating and maintenance of uniform temperature; precise position control of levitated samples particularly in a gaseous environment; measurement and control as well as reduction or elimination of sample rotation in featureless samples; measurement of the emissivity of pure metals, alloys, oxides and ceramics; and measurement of the materials work function over a range of temperatures.
- Microgravity furnace and experiment instrumentation technologies to better monitor sample health (temperature, pressure, etc.) and experiment status while minimizing the instrumentation's effect on the sample as well as reducing system impacts on experiment design; additionally, consideration should be given to extending the useful life of instrumentation in order to minimize the need for on-orbit recalibration and refurbishment/replacement.
- Microgravity furnace and experiment thermal technology such as improved insulation for minimizing power, volume, mass and complexity; improved high temperature thermal interface materials for transferring the heat into and out of the sample and furnace components (which are stationary or move relative to each other); heating and cooling approaches that enhance safety, science and resource utilization.
- Advanced technologies for providing safe, efficient sample containment while enhancing scientific return and minimizing system impacts on furnace and experiment system design.

B1.03 Biomolecular Systems, Devices and Technologies
Lead Center: JPL
Participating Center(s): ARC, MSFC

In this subtopic, NASA recognizes that biomolecular approaches promise to enable lightweight, convenient, and highly focused therapies. Three key technologies form the cornerstones of NASA's Biomolecular Systems Program: nanotechnology, information technology, and biotechnology. Investment in these fast-moving fields will provide leading edge advances in health care that will benefit humans on Earth and in space. The program conducts basic research and develops breakthrough technologies to deliver prototype biomolecular micrometer and nanometer scale systems for the detection, imaging, recognition and monitoring of biological signatures and processes at the molecular level. This research program will support NASA's medical, diagnostic, and clinical objectives for long-duration space flight, including commercial applications on Earth.

Biomolecular Sensor and Effectors
Emerging technology for micrometer and nanometer scale materials fabrication, manipulation, and characterization enables a new range of technological possibilities. Of particular interest are techniques for miniaturizing biochemical analysis instruments that can interact with life and its constituents at the molecular scale. One of the NASA goals is to seek out and identify biochemicals in minute concentrations in the human body and in extraterrestrial settings. Initially, these microscopic devices, engineered on the molecular scale, will function primarily to gather data about their environment, with the ultimate goal of actively responding to threats to astronaut health (e.g., by killing tumor cells or by targeted delivery of medication).

Microelectromechanical Systems (MEMS) technology has enabled numerous innovative methods to miniaturize biomedical instruments. Microfluidic platforms are essential to the goals of detecting molecular signatures of real-time biological activities in the human body. Finally, investigations of nanoscale materials, such as carbon nanotubes, and their fabrication techniques are needed to develop biochemical devices with new capabilities with implications beyond miniaturization.

Areas of Technology Development
- In vivo sample acquisition and processing
- In vivo device propulsion
- Wireless communications for micro/nano biochemical instruments
- Power sources (biochemical, electrochemical)
- Self-assembled fabrication techniques for biochemical sensor arrays
- Other technologies which would contribute toward integrated prototype nano-explorers (combining sample acquisition, processing, and sensing)
- Integrated in vivo biochemical sensor and targeted drug delivery devices

Biomolecular Imaging
Cellular structures and functions are a marvel in architecture, engineering, and programming. Currently there are various imaging techniques which allow us to obtain concentration variations, map compositions, and monitor transport and transduction mechanisms. Cellular biologists now use molecular imaging to localize and image which biological molecules are where inside a cell and its structures. In addition to where, we can also image when molecules are produced to track temporal changes in cell metabolism. Current technologies for molecular imaging in cellular biology would include the following: FISH, GFP, MRI and spectral techniques that allow spectrally multiplexed probes. Atomic, chemical force microscopies, carbon nanotube and proximal probes are all examples of new approaches to resolving molecular structure at a small enough scale to image individual atoms. Photon based imaging from infrared to x-ray, PET, MRI, NSOM, STM/AFM, photo-acoustic imaging, IR spectral imaging are just some examples of imaging techniques. Innovation is sought in the following:

- New technologies for imaging protein expression in cells at or below the diffraction limited spatial resolution of optical microscopies
- Nanoscale imaging at a resolution sufficient to provide protein or DNA sequence
- Image cellular activities such as gene expression at a molecular scale
- Nanoscale imaging at a resolution sufficient to provide protein or DNA spatial configuration

Biosignatures
Fundamental to the success of the NASA goals is the ability to identify biosignatures to distinguish life from non-life on a planetary scale. Life is a thermodynamic enigma - seemingly violating thermodynamic laws by decreasing entropy. This ability comes from its ability to extract energy from the environment and use this energy to build structures and establish chemistries that are decidedly out of equilibrium. The combination of structural and chemical disequilibria, along with the resulting changes in the environment due to consumption and production of

materials make the search for life rather straightforward - utilizing thermodynamics and kinetics. Search over a variety of scales for structures, measure the chemistry of these structures, and search for metabolites that are disappearing or accumulating on a variety of time scales. Using such an approach, we imagine that life can be sought in a wide variety of environments, including the human body, simply by making simple measurements and asking the right questions of the data. NASA requires technology for in situ life detection that will provide a springboard for the use of similar approaches for detection of "unhealthy" subjects, be they unhealthy due to bacterial or viral infections, or malignancies. From this perspective, one can readily identify specific methods and approaches that will be used in astrobiology (things to be measured, statistical approaches, data handling and analyses, etc.), and how they might be adapted to laboratory, environmental, and in situ studies of life detection, and eventually to laboratory and clinical methods of diagnosis.

Areas of Technology Development
- Tools to assist in the identification of signatures of life via thermodynamic and kinetics of metabolism
- Detection of molecular level structures and anomalies
- Detection of chemical disequilibria and microscale chemical analyses

Biomolecular Signal Amplification
The ability to detect weak signals emitted from molecular interactions has always been a challenge for molecular biologists. Such signals highlight numerous important interactions such as antigen-antibody associations and nucleic acid hybridization reactions. These interactions are often used as assays to detect molecular indicators of disease pathology. As such, increasing sensitivity of these assays without compromising accuracy is of utmost importance. Traditionally, signal amplification in molecular biology has been achieved by one of two approaches- either amplification of the molecule to be detected or intensifying the signal from the detector molecule. Reverse Transcriptase Polymerase Chain Reaction (RT-PCR) is an example of the former. In RT-PCR, one makes a DNA copy of a low copy number transcript to be detected, then amplifies the number of molecules by PCR before detecting the products. To illustrate increasing the signal from a detection molecule, consider the use of labeled secondary antibodies to enhance signal from primary antibody binding. While these techniques have improved detection, methods are still limiting when it comes to detecting molecules in very small quantity or in single copy. More recent examples include catalyzed reporter deposition (CARD), branched DNA signal amplification assays and Fluorescent Resonance Energy Transfer (FRET).

Areas of Technology Development
- Single, specific molecule detection among high background noise
- Contrast and sensitivity enhancers for non-invasive, real-time imaging
- Utilization of biological amplification or self-amplification of target molecules
- Amplification methods to enhance the probability of finding target molecules
- Amplification of the precursors of ailments (fever, infections, bone loss, muscle atrophy, etc.)
- Utilization of biological amplification or self-amplification for ailments

Nano/Quantum Devices
Nanostructure science and technology is a broad and interdisciplinary area of research and development activity that has been growing explosively in the past few years. It has the potential for revolutionizing the ways in which materials and devices are created and the range and nature of functionalities that can be accessed. Nanodevices or devices based on quantum effects have the potential for higher performance at lower volume, weight, and power consumption.

Areas of Technology Development
- Innovative synthesis and assembly techniques of nanostructured materials for device applications, including semiconductor nanostructures, metallic/magnetic nanostructures, and carbon nanotubes.
- Innovative growth and formation techniques of semiconductor quantum dots with greater uniformity of size, controllable achievement of higher quantum dot density, and closer dot-to-dot interaction range.
- Modeling, simulation and demonstration of innovative sensor concepts based on development of novel applications of nanotechnology and quantum mechanics.
- Innovative nanoscale functional device building blocks based on single electron charging. Innovative nano-devices for sensor applications.

- Nanomagnetic devices
- Molecular electronics

B2 Fundamental Space Biology

Fundamental Biology (FB) is NASA's agency-wide program for the study of fundamental biological processes through space flight and ground-based research. The program has three primary goals: (1) Effectively use the microgravity and other unique characteristics of the space environment to enhance our understanding of fundamental biological processes (2) Develop the scientific and technological foundations for a safe, productive human presence in space for extended periods and in preparation for further exploration (3) Apply this knowledge and technology to improve our nation's competitiveness, education, and the quality of life on Earth. Increased emphasis is placed on cell and molecular biology and developmental biology, as well as on the growing disciplines of evolutionary biology and genomics. FB will participate in the expanded range of space missions the Agency will undertake in the future. These include the International Space Station, planetary probes, surface studies, sample returns, and planetary bases. The Biological and Physical Research Enterprise also seeks to engage the commercial sector in exploiting the economic benefits of fundamental space biology on Earth.

B2.01 Understanding and Utilizing Gravitational Effects on Plants and Animals
Lead Center: ARC
Participating Center(s): KSC

This subtopic area focuses on technologies that support the NASA Fundamental Biology Program in understanding the effects of gravity on plants and animals. The program supports investigations into the ways in which fundamental biological processes function in space, compared to their function on the ground. To conduct these investigations, the program supports both ground and space flight research. The improved understanding of the role of gravity on plants requires innovative support equipment for observing, measuring, and manipulating the responses of plants to environmental variables. Areas of innovative technology development include:

- Measuring the atmospheric and radiation environment and optimizing the lighting and nutrient delivery systems for plants.
- Innovative technologies for storage, transportation, maintenance, and in situ analyses of seeds and growing plants.
- Sensors with low power requirements and low mass to monitor the atmosphere and water (nutrient) environment, as well as automated control and data logging systems for the experiment containers to measure performance indicators, such as respiration (whole plant, shoot, root), evapotranspiration, photosynthesis, and other variables in plants.
- Data analysis and control.
- Modular seeding and/or planting units to minimize labor.
- Sensors for atmospheric, liquid and solid analyses, including atmospheric and liquid contaminants such as ethylene and other biogenic compounds as well as analyses of hydroponic and solid media for N, P, K, Cu, Mg and micronutrients.
- Remote sensors to identify biological stress.
- Expert control systems for environmental chambers.

The improved understanding of the role of gravity on animals requires innovative instrumentation which tracks and analyzes from organism development, including gametogenesis through fertilization, embryonic development and maturation, through ecological system stability. Technologies may incorporate a variety of processes such as metabolism and metabolic control, through genetic expression and the control of development. Of particular interest are technologies that require minimal power and can non-invasively measure physical, chemical, metabolical and development parameters. Such measurements will ultimately be made in environments at one or more of several gravity ranges, e.g., "microgravity" (.01 to .000001 g), "planetary" gravity (1 g (Earth); 0.38 g (Mars) or 0.12 g (Moon)) or hypergravity (up to 2 g). But, refined and stable measurements are as important as gravity independence. Of interest are sustained instrument sensitivity, accuracy and stability, and reductions in the need for frequent measurement standardization. Parameters requiring measurement include pH, temperature, pressure, ionic strength, gas concentration (O_2, CO_2, CO, NO_2, etc.), and solute concentration (e.g., Na^+, K^+, Ca^{2+}, Mg^{2+}, SO_4^{2-}, Cl^-, PO_4^{3-}, etc.). In the case of new techniques and instruments, a clear path toward miniaturization, reduction in power demands and increased space worthiness should be identified. Interests applicable to plant, microorganism, and animal study applications include:

- Expert data management systems
- Capabilities for specimen storage, manipulation and dissection
- Video-image analysis for specimen (cell, animal, plant) health and maintenance
- Sensors for primary environmental parameters and microbial organisms
- Electro-physiology sensors, biotelemetry systems and biological monitors carried on spacecraft

B2.02 Biological Instrumentation
Lead Center: ARC
Participating Center(s): None

The Fundamental Biology Program (FB) is the Agency lead for biological research and biological instrumentation/technology development, and focuses on research designed to develop our understanding of the role of gravity in the evolution, development, and function of biological processes. Increasingly the research thrusts are directed at incorporating the most advanced technologies from the fields of cell and molecular biology, genomics, and biotechnology, to provide researchers with the most-up-to-date methods to conduct their biological research. For these requirements, the capability to perform autonomous, in situ acquisition, preparation and analysis of samples to determine the presence and composition of biological components is a highly desired objective. As the size of flight payloads becomes increasingly smaller, and information technologies permit smarter and more independent payload and device control and management, the realization of completely autonomous in situ biological laboratories (ISBL) on spacecraft platforms and planetary surfaces will become more desirable.

Biological and biomolecular/microbiological /genomic research is enabling unprecedented insight into the structure and function of cells, organisms, and sub-cellular components and elements, and a window into the inner workings and machinations of living things. Techniques and technologies, which have evolved from the microelectronics and biological revolutions, have permitted the emergence of a new class of instruments and devices. Many devices, techniques and products are now available or emerging which allow measurement, imaging, analysis and interpretation of the biological composition at the molecular level, and which permit determination of DNA/RNA and other analytes of interest. Advances in information systems and technologies, and bioinformatics, provide the capability to understand, simulate, and interpret the large amounts of complex data being made available from these biological-physical hybrid systems. These synergistic relationships are facilitating the development of revolutionary technologies in many areas.

Biological instrumentation technologies to support FB objectives are grouped into the following solicited categories:

- Biological sample management and handling - Technologies for remote, automated biosample and biospecimen collection, handling, preservation/fixation, and processing. Modular, embeddable systems and subsystems capable of supporting a variety of tissue, liquid, and/or cellular specimens, from a wide range of biological subjects, including cells, nematodes, plants, fish, avians, mice, rats, and humans.
- In situ measurement and control - Technology development for in sensors, signal processors, biotelemetry systems, sample management and handling systems, and other instruments and platforms for real-time monitoring and characterization of biological and physiological phenomena.
- Genomics technologies - Technologies to enhance and augment research in genomics, proteomics, cell and molecular biology, including molecular and nano-technologies, cDNA arrays, gene array technologies, and cell culture and related habitat systems.
- Bio-imaging systems - Advanced, real-time capabilities for visualization, imaging, and optical characterization of biological systems. Technologies include multi-dimensional fluorescent microscopy, spectroscopy systems, and multi- and hyperspectral imaging.
- Biological information processing- Capability for automated acquisition, processing, analysis, communication, and archival and retrieval of biological data, and interface/transfer to advanced bioinformatics and biocomputation systems.

- Integrated biological research systems and subsystems**-** Integrated, experiment/subject specific biolaboratory modules and systems, providing complete flight prototype capability to support the above five categories.

B2.03 Understanding and Utilizing Gravitational Effects on Molecular Biology and for Medical Applications
Lead Center: JSC
Participating Center(s): ARC

Microgravity allows unique studies of the effects of gravitational effects on cell and tissue development and behavior. These studies utilize novel and advanced technologies to culture and nurture cells and tissues. Additionally, the ability to manipulate and/or exploit the form and function of living cells and tissues has significant potential to enhance the quality of life on Earth and in space through novel products and services, as well as through new science knowledge generated and communicated. This capability may lead to new products and services for medicine and biology. Current space research includes new methods for purification of living cells; development of space bioreactors for culture of fragile cells that have applications in biomedical and cancer research; tissue engineering systems which take advantage of microgravity to grow 3-D tissue constructs; testing the effectiveness of drugs and biomodulators on growth and physiology of normal and transformed cells, and methods for measuring specific cellular and systemic immune functions of persons under physiological stress. Biotechnology research systems also are being developed for micro-g research on the International Space Station.

Specific areas of interest for technology innovation are:

- Techniques and technologies for culturing mammalian cells in bioreactors, including advanced bioreactor designs and support systems, miniature sensors for measurement of pH, oxygen, carbon-dioxide, glucose, metabolites, and microprocessor controllers.
- Instrumentation for separation and purification of living cells, proteins and biomaterials, especially those using electrokinetic or magnetic fields that obviate thermal convection and sedimentation, enhance phase partitioning, or use laser light and other force fields to manipulate target cells or biomaterials.
- Techniques or apparatus for macro-molecular assembly of biological membranes, bio-polymers, and molecular bio-processing systems; bio-compatible materials, devices, and sensors for implantable medical applications including molecular diagnostics, in vivo physiological monitoring and microprocessor control of prosthetic devices.
- Methods and apparatus which allow microscopic imaging and biophysical measurements of cell functions, effects of electric or magnetic fields, photoactivation, and testing of drugs or biocompatible polymers on live tissues.
- Quantitative applications of molecular biology, fluorescence image and flow cytometry, and new methods for measurement of cell metabolism, cytogenetics, immune cell functions, DNA, RNA, oglionuceotides, intracellular proteins, secretory products, and cytokine or other cell surface receptors.
- Micro-encapsulation of drugs, radiocontrast agents, crystals, and development of novel drug delivery systems wherein immiscible liquid interactions, electrostatic coating methods, and drug release kinetics from microcapsules or liposomes can be altered under microgravity to better understand and improve manufacturing processes on Earth. This includes production technologies for improving the controlled release from transdermal drug devices, ionaphoresis, controlled hyperthermia and new drug delivery systems for inhalation and intranasal administration. Also microencapsulation of cells for transplantation into patients.
- Miniature bioprocessing systems which allow for precise control of multiple environmental parameters such as low level fluid shear, thermal, pH, conductivity, external electromagnetic fields and narrow-band light for fluorescence or photoactivation of biological systems.
- Low-temperature sample storage (-80^{o}C) and biological sample preservation instrumentation.

B3 Biomedical and Human Support Research

The goal of the Biological and Human Support Research topic is innovations to ensure the health, safety, and performance of humans living and working in space. This includes life support functions such as a healthy air and water supply, food for the crew in future ultra-long duration missions, health maintenance and in-space medical care, radiation shielding for protecting humans in deep space missions, and unique human factors issues of the space environment. BPR seeks to engage the commercial sector in exploiting the economic benefits of biomedical and human support research on Earth. Also sought, in terms of veterinary animal health, are life support functions for animals that may be on the mission for research or other purposes.

B3.01 Advanced Spacecraft Life Support
Lead Center: JSC
Participating Center(s): ARC, JPL, KSC, MSFC

Advanced life support systems are essential to enable human planetary exploration. Future life support systems must provide additional closure of life support systems to further reduce mass and to promote self-sufficiency. Requirements include safe operability in micro-and partial-gravity, high reliability, minimal use of expendables, ease of maintenance, and low system volume, mass, and power. Innovative, efficient, practical concepts are needed in all areas of regenerative processes providing the basic life-support functions of air revitalization, water reclamation, waste management, as well as sensors and controls. Also innovative, cost-effective flight experiment concepts are desired to understand the effect of microgravity and partial-gravity on the operation and performance of advanced life support technologies. In addition to these space exploration related applications, innovative regenerative life support approaches that could have terrestrial application are encouraged. Phase I proof of concept should lead to Phase II hardware development that could be integrated into a life support system test bed. Proposals should include estimates for power, volume, mass, crew time requirements, as well as an analysis of how the concept will impact other systems. Areas in which innovations are solicited include the following:

Air Revitalization. Oxygen, carbon dioxide, water vapor, and trace gas contaminant concentration, separation, and control technologies.

- Separation of carbon dioxide from a mixture primarily of nitrogen, oxygen, and water vapor to maintain carbon dioxide concentrations below 0.3 percent by volume.
- Removal of trace contaminant gases from cabin air using advanced regenerable sorbent materials, improved oxidation techniques or other methods.
- Alternate methods of storage and delivery of atmospheric gases to reduce mass and volume and improve safety compared to 4300 psia tank storage that has a wt penalty of 0.56 lbm of tank weight per lb of N2 stored.
- Alternate methods of atmospheric humidity control that do not use liquid-to-air heat exchanger technology (dependent upon the spacecraft active thermal control system) or mechanical refrigeration technology. Design metabolic latent load is 2.277 kg of water vapor per person per day.

Water Reclamation. Efficient, direct treatment of wastewater, consisting of urine, wash water, and condensates, to produce potable and hygiene water.

- Technologies for the phase separation of solids, gases and liquids in a microgravity environment that are insensitive to fouling mechanisms.
- Technologies to improve the transport of wastewater fluids, particularly the elimination or management of solids precipitation in wastewater lines
- Technologies for the treatment of brine solutions.
- Post-treatment technologies to reduce the total organic carbon from 100 mg/l to less than 0.25 mg/l in the presence of 50 mg/l bicarbonate ions, 25 ppm ammonium ions and 25 ppm other inorganic ions.
- Physicochemical technologies for primary treatment to reduce the total organic carbon concentration of the wastewater from 1000 mg/l to less than 50 mg/l and the total dissolved solids from 1000 mg/l to less than 100 mg/l.
- Technologies to minimize biofilm formation on fluid handling components, including flowmeters, checkvalves, regulators, etc.
- Efficient techniques to minimize or attenuate the acoustic and micro-g vibration emissions from rotating equipment.

Waste Management. Present focus is on initial human mission scenarios beyond space station (i.e., limited plant production). Estimated waste generation rates for a 180-day transit and 600-day exploration mission (kg/day for a 6-

person crew) include the following: trash (0.56), food packaging (2.02 - 7.91), dry human fecal wastes (0.72), inedible plant biomass (1.69 - 5.45), paper (1.16), tape (0.25), and filters (0.33).

- Long duration storage and containment for dry and wet trash, biodegradable and bio-hazardous materials.
- Recovery of water from wet wastes including both human fecal waste and bio-hazardous wastes.
- Stabilization and disinfection technologies to minimize hazards associated with wet wastes.
- Compaction of wet and dry wastes.
- Particle size reduction for preprocessing wastes to 100 microns or smaller.
- Waste processing techniques such as aerobic and anaerobic biodigestion, wet oxidation, pyrolysis, supercritical oxidation, steam reforming, and incineration.
- Product and by-product post-treatment technologies that eliminate (1) undesirable by-products such as nitric oxide and sulfur dioxide from a high temperature oxidative process (e.g., incineration), and (2) treatment of biological and physicochemical reactor residues (incinerator, composting process, etc.) for reuse and/or long duration storage.

Sensors. Significant improvements in miniaturization, accuracy, operational reliability, real-time multiple measurement functions, in-line operation, self-calibration, reduction of expendables, and low energy consumption for monitoring and control of the life support processes. Sensitive, fast response, on-line analytical sensors to monitor suspended liquid droplets, dispersed gas bubbles and water quality, particularly total organic carbon. Other species of interest include dissolved gases and ions in water reclamation processes, and atmospheric gaseous constituents (oxygen, carbon dioxide, water vapor, and trace gas contaminants) in air revitalization processes. Both invasive and non-invasive techniques will be considered.

B3.02 Space Human Factors and Habitability
Lead Center: JSC
Participating Center(s): None

The goal of this subtopic is to develop innovative concepts to improve human-systems interactions and analysis of human-system interfaces, and to develop innovations in crew accommodations, equipment, and computer-based support. The long-term goal is to enable complex, future human space missions of up to 5 years without resupply, and with minimal ground support.

This subtopic seeks technology innovations that will help address the following questions:

- What habitability factors and working conditions are essential for crew well-being?
- How can habitability factors and their effects on the crew be measured?
- How can potential spacecraft environments and operational procedures be modeled to predict their effects on the crew?
- How can human-system interfaces be designed and evaluated for effectiveness and usability in a cost-effective and reliable manner?

Proposals are sought for innovations that improve human-systems interactions and analysis of human-system interfaces, and to develop innovations in crew accommodations, equipment, and computer-based support. Examples of specific needs are:

- Automated analysis of video data for categorization and editing purposes. Using videotapes or live video, automatically analyze images and categorize crew activities. Report start and stop times, durations, and frequencies of selected activities, such as translation, working at a fixed location, use of a specific tool or access to a certain panel.
- Computer-based analysis of computer-user interfaces for complex display systems to provide a means to conduct objective (unbiased) review of the displays and to determine the noncompliance to guidelines and standards and consistency and commonality across different systems. The tool should have the capability to generate a report and to reference the specific guidelines or standards violated and recommend corrective actions. Two types of automated metrics can be used:

- task-sensitive metrics (interfaces appropriate for user tasks)
- layout-appropriateness (efficiency of the organization of the objects based on size, distance, and frequency of use)

- New technology for illumination modeling with particular attention to real-time displays of shadowing, glare and bloom combined with predicted energy distribution values to quantify surface illumination and reflection. New technology for illumination measurements and evaluations such as "smart" sensor technology for measurement of illumination, color and surface reflectivity.
- Crew and equipment restraint concepts: Develop design concepts and prototypes for multi-purpose crew or equipment restraining devices. These devices should provide easy set-up and disassembly (design goal < 5 minutes) with easy adjustments (no more than four points of adjustment). Restraints should be usable at any habitable location of space vehicle such as work sites, payload rack, crew quarters. They may have standard ISS attachment interfaces, or innovative methods of attachment. Adjustability for a wide range of sizes is required. Specifically, crew restraints must accommodate users from 5th percentile Japanese female (about 149 cm stature) to 95th percentile American male (about 190 cm stature). Equipment restraints should be able to hold items of various sizes and shapes in user selected positions and attitudes.
- Biomechanics and anthropometry data collection and analysis: Develop size or motion measurement systems using wireless or clothing-mounted sensors or remote sensors. Systems should analyze input and produce biomechanical and anthropometry output accurate to +/-5 percent of dimension. Donning, adjustments, field calibration, and field maintenance time should insure ease, practicality, and acceptance by the user (design goal < 3 minutes). Examples of desired data outputs include reach limits, joint angles, work envelopes; positions, forces, torques, impulses exerted between equipment and user; characterization of gait or translation mechanics, and energy analyses. System should work in confined volumes, and, as a design goal, inside protective clothing such as extravehicular activity suits.
- Human accommodations: Develop design concepts and prototype systems for laundry and dishwashing tasks. The systems should be suitable for operation in low-gravity and/or microgravity environments. Requirements include low water consumption and minimal trace gas emissions.

B3.03 Human Health Maintenance, Adaptation, and Countermeasures
Lead Center: JSC
Participating Center(s): ARC, JPL

Human presence in space requires an understanding of the effects of microgravity and other components of the space environment on the physiological systems of the body and on the psychology of the crew. A variety of environmental monitoring and biomedical activities to protect crew health and to counter the effects of space on human physiology is required. Countermeasures must be developed to oppose the deleterious changes that occur in space or upon return to Earth. Health care and medical intervention also must be provided over extended duration missions. As launch costs are extremely sensitive to mass and volume, sensors and instruments must be small and light with an emphasis on multi-functional aspects. Low power consumption is a major consideration, as are design enhancements to improve the operation, design reliability, and maintainability of these instruments in microgravity. As the efficient utilization of time is extremely important, innovative instrumentation setup, ease of usage, improved astronaut (patient) comfort, non-invasive sensors, and easy-to-read information displays are all-important considerations.

Major technology development disciplines include: endocrinology, immunology, hematology, microbiology, muscle physiology, pharmacology, drug delivery systems, and mechanistic changes in neurovestibular, cardiovascular, and pulmonary physiology.

Human Health Monitoring and Countermeasures

- Technologies to monitor physical activity and loads placed on different segments of the human body.
- Approaches for sustaining, maximizing, assessing, and modeling individual as well as team performance.
- Technologies for assessment of gas bubble formation or growth in the body after in-flight or ground-based decompression, and to prevent or minimize associated decompression sickness.
- Approaches to achieve health care and intervention within the operational constraints of space flight, including pharmaceuticals having extended shelf-life, and non-invasive diagnostic methods and procedures, medical monitoring, dental care and surgery, and blood replacement technology.

- In-flight procedures and techniques for assessing the human metabolism of proteins, carbohydrates, lipids, vitamins, and minerals.
- In-flight analysis to evaluate physiological and metabolic and pharmacological responses of astronauts.
- Development of virtual training tools to enhance adaptability of sensory-motor functions.

Non-invasive Instrumentation

- Instrumentation to be used for in-flight and ground-based studies for reliable and accurate non-invasive monitoring of human physiological functions such as the cardiovascular, musculoskeletal, neurological, gastrointestinal, pulmonary, immuno-hematological, and hematological systems.
- Instruments to provide (1) quantitative data to establish the effectiveness of an exercise regimen in ground-based research and (2) measure of bone strain in the hip, heel, and lumbar spine during exercise.
- Smart sensors capable of sensor data processing and sensor reconfiguration.
- Ultrasonic doppler systems for blood flow analysis.
- Virtual medical instrumentation.
- Automated biomedical analysis.
- Analyzers for measurement of blood, urine, and respiratory gas volumes in microgravity.
- Non-invasive, biosensors for real-time monitoring blood chemistry, gases, calcium ions, electrolytes, cellular components, proteins, lipids, and hormones.
- Real time, in vitro, urine chemistry sensors for automated urine chemistry analysis in a smart toilet.

B3.04 Spacecraft/Environmental Monitoring for Crew Health
Lead Center: JSC
Participating Center(s): JPL

Long-term human space missions require continuous environmental monitoring to protect crew health. Research disciplines include analytical chemistry, environmental microbiology, nutrition, radiation biology, and toxicology. Quantitative assessments require innovative, space flight-compatible approaches for environmental health monitoring. Special instruments are needed to assess the overall acceptability of the environment for human habitation. In addition, instrumentation is needed for measuring thresholds for unacceptable atmospheric contamination levels and for assessing associated risks. Current specific areas of interest include:

- Real-time and quantitative broad spectrum or target compound-specific analyzers for trace contaminants in spacecraft atmospheres. These instruments must be compact, feature low power consumption, low maintenance, a high level of automation (requiring minimal crew intervention) and operate with high stability. To be useful in the spacecraft environment, these devices must show specificity to compound identification and sensitivity to levels of contaminants well below exposure guidelines (SMAC's). Hydrogen cyanide, ammonia and formaldehyde are contaminants of high current interest.
- Maintenance of microbial quality of the atmosphere, water and surfaces during space flight and means of assessing their effectiveness, including new clinical microbiology methods for rapid identification of environmental pathogens, methods for measuring bio-films and novel systems for sterilization.

B3.05 Maintaining Individual and Team Performance
Lead Center: JSC
Participating Center(s): None

Human physical and cognitive performance capabilities vary over time. Short-term performance deterioration occurs due to fatigue and such phenomena as "vigilance decrements" but, given appropriate conditions (rest, diet, alternative activity), recovery is usually complete. Indeed optimal physical and cognitive loading usually leads to longer-term improvement - learning. "Forgetting" is also a common cause of performance failure and this can be reduced or compensated for by appropriate training, task design and job aids. Inappropriate conditions, such as those that may be found during long duration space flight under hostile environments and the ever-present stress of isolation may give rise to greater and, perhaps permanent, degradation of performance capability.

The challenge to the space human factors community is to create conditions that minimize the occurrence and effects of performance decrement. The first step in the management of individual and team performance is to *moni-*

tor available predictors of performance capability. The second step is to *design* environments, tasks, job aids and operational schedules that reduce long-term degradation. The third step is to intervene by introducing *training* opportunities that complement and supplement the routine demands. The fourth step is to *evaluate* the effectiveness of the first three steps so that future missions may benefit fully from the experience. These fundamental steps - monitoring, design, training and evaluation - may be supported by *modeling* and simulation so that factors that are likely to influence performance capability can be investigated under minimal risk conditions.

This SBIR subtopic is aimed at the *development of technology* that will aid study, modeling and implementation of measures to preserve individual and team performance capability over extended space missions. The following categories and associated examples indicate some *specific development projects* that the NASA Space Human Factors community believes will help in the design of successful extended space missions.

Monitoring
Minimally invasive and unobtrusive devices and techniques that may be used to monitor the *physiological and psychological states* of individuals during long duration space flights or simulations.

Examples of such devices would include compact electrophysiological monitors that collect and analyze key parameters and indicate appropriate countermeasures - such as diet and exercise regimes. Psychological state monitors would include EEG, sensory-motor performance, attention and other cognitive performance batteries with analysis and personal feedback.

Minimally invasive and unobtrusive devices and techniques that may be used to monitor the *behavior and performance* of individuals and teams during long duration space flights or simulations.

Examples of such devices would include semi automated human activity / behavior monitors, with embedded analysis, diagnostic and prescription capabilities. Other useful devices would be system-based monitors of individual and team responses to varying system states. Such automated monitoring of individual and team behavior and performance and "psycho-social stability" could provide calibration and trend information regarding readiness to perform. These devices could also be applied to the measurement of productivity and task outcome quality.

Design
Information systems and interfaces that will aid users in their management of complex operations such as maintenance and research.

Just-in-time system and operation information systems tailored to aid the human user during the conduct of routine and emergency operations and activities. Examples would include effective and efficient job aids such as "intelligent" manuals, checklists, warnings and instructions for the major subsystems (environmental control, docking, food processing, extravehicular activity etc.)

Electronic devices, such as PDAs and web-based systems, that provide flexible interfaces between users and large information systems.

Physical environments and equipment that are conducive to the conduct of individual and group operational, maintenance, exercise and research activities.

Flexible habitat and multi-purpose, modular equipment designs that provide opportunities for variety and allow individuals and groups to work, carry out research, exercise, study, play and relax during long duration missions and simulations. Such habitat designs would also include opportunities to vary spatial, visual, acoustic and thermal environments.

Trouble shooting, maintenance and repair aids and procedures that support crews in dealing with equipment and medical emergencies.

Flexible operational schedule monitors that are aimed at detecting the likelihood of long-term performance capability degradation.

Monitored but flexible computer based physical, training, research, maintenance and recreational schedule monitors, for individuals and teams, aimed at maintaining high levels of physical and cognitive readiness.

Training
Physical training facilities and programs that are aimed at offsetting the stresses of long duration space flight.

Innovative and flexible exercise equipment and associated regimes and certification processes that address musculo-skeletal, cardiovascular and motor skill capabilities while maintaining high levels of performance feedback and motivation.

Mission oriented training facilities, programs and schedules that are aimed at maintaining high levels of operational readiness.

Baseline and just-in-time training and self-assessment simulation facilities and certification processes that assure competence (skills, knowledge) to deal with research, maintenance and operational demands such as construction, exploration and equipment and medical emergencies.

Evaluation
Development of *equipment, methods and databases* that may be used to formally evaluate the utility of intervention strategies aimed at the minimization of human performance degradation during long duration space explorations or simulations.

"Lessons learned" and "voice of the customer" data capture and analysis facilities and processes that monitor individual and crew actions, effects and self assessments of capability status.

Modeling
Development of *physical analogs (simulators)* that may be used to study the effects of long duration missions as well as to prepare individuals and teams for such missions.

Innovative development and adaptation of facilities and situations that mimic the spatial, environmental (acoustic, visual, gravitational, pressure), task and operational characteristics of long duration space exploration missions that can be used both to investigate human behavior and performance and as training devices.

Development of *digital models of human environments, performance and behavior* that may be used to simulate those factors that contribute to long-term performance capability maintenance or degradation.

Computer simulations of individual and group behavior and performance that can be used to explore the conditions conducive to performance degradation. Such devices would include digital human models and simulations of operational environments and routine and emergency tasks.

B3.06 Space Medicine and Health Care Systems
Lead Center: JSC
Participating Center(s): None

NASA seeks innovative proposals covering two small areas in Space Medicine and Health Care Systems for future space missions. These areas are: (1) wireless LAN technologies with software-configurable physiological monitoring and (2) portable, collapsible, hyperbaric therapy. The mass and volume of medical equipment and consumables will be extremely constrained in future ultra-long duration missions, such as to the Moon or Mars. Power consumption will also be a consideration, but of a lesser order. Health Care Systems must be operated in medical emergencies by astronauts, who may be non-medical professionals with limited medical training. In a Mars mission, for example, round trip radio communications delays of 6 to 40 minutes makes support from terrestrial physicians an impossibility for time-critical medical emergencies.

Innovative Wireless LAN Technologies With Software-Configurable Physiological Monitoring: Except in infrequent, special medical flight experiments (which collect multiple physiological measurements over a short time) and during EVAs (where ECG is monitored), routine, continuous, medical monitoring of astronauts is currently not done in space. Limited crew time, as well as crew comfort requirements, make the daily application of sensors and electrodes with a multitude of wires very undesirable, so a few hours or days per month may be all that is available for routine monitoring or medical experiments. In nominal activities, the rigorous workload of astronauts requires that physiological monitoring equipment be extremely non-intrusive, yet rugged. In emergencies, crew comfort and patient movement also require a non-intrusive, rugged system. During medical emergencies, a continuous stream of multi-channel physiological data from more than one injured astronaut may need to be collected and processed throughout the crisis.

In ultra-long duration missions to Mars or the Moon, physiological monitoring of astronauts may detect problems and suggest appropriate countermeasures, long before there is serious damage to crew health or greatly decreased crew performance. Additionally, a rapidly deployable, general purpose, individual physiological monitoring system would be a key component of an emergency medical system for serious injuries or illnesses, such as radiation sickness, trauma, or severe injuries from fire or chemical burns, as well as in surgical monitoring.

Whether in routine or emergency monitoring, an individual physiological data acquisition system would be wirelessly linked to computers and clinical laboratory equipment in the spacecraft equipment racks. Attending crew members would interface with computers in the spacecraft racks through RF-linked portable digital assistants (PDAs) to view wireless patient data, and to enter data into the medical record by hand.

Enabling technologies for creating such a system are needed. *All physiological input data should be simulated or modeled (no human subjects).* Technology innovations are needed in the following areas:

- A Wireless-LAN-based physiological data acquisition system that is adaptable to emergency response, as well as routine physiological monitoring, in human space exploration missions. Rapid software reconfiguration for different input signals should be based on digital processing rather than unwieldy hardware solutions. However, sophisticated data interpretation by intelligent systems will likely occur primarily in computers in spacecraft racks to conserve battery power in the wireless unit. The ability to operate in the noisy electromagnetic environment of a spacecraft is important, and transmission distances should be at least 4 meters.
- A software system that can process physiological data from several astronauts received across a wireless LAN, during both critical emergencies and more routine monitoring. Assume data from blood tests and other clinical laboratory equipment is available across the LAN. The software system would organize data from more than one astronaut at a time. It should extract physiologically important features in the data, compare current data to past medical records, and provide a clear visualization of the data to attendant crew members via a commercially available, RF-linked PDA.

Portable, Collapsible Hyperbaric Therapy for the Human Exploration of Space
Extra-Vehicular Activity (EVA) suits, whether used on planetary surfaces or in the vacuum of space, are essentially one-person, independent spacecrafts. To preserve mobility and to allow them to be made of thinner and less stiff fabrics, EVA suits are operated at pressures much lower than 1 atmosphere (14.7 psi). EVA suits in the United States space program operate at slightly above 4 psi. During decompression, Nitrogen gas bubbles can form in body fluids, thereby damaging tissues and causing the symptoms of Decompression Sickness. To prepare for an EVA, crewmembers pre-breathe 100 percent oxygen to flush out as much Nitrogen from the body as possible. This lowers the risk of Decompression Sickness, which can be treated by use of a hyperbaric chamber, re-breathing 100 percent oxygen, and considerable medical judgment.

Enabling technologies for creating a space-flight compatible system for hyperbaric therapy are needed. Mass and volume are severely limited in space exploration missions. Reasonable power consumption is also desired. *All physiological input data should be simulated or modeled (no human subjects).* Innovations are needed in the following areas:

- A portable, collapsible/inflatable chamber to be pressurized and maintained at about 3 atmospheres during use, including a pressure controller and simple interfaces for physiological monitoring and oxygen re-breathing. Single crew or multi-crew chamber designs can be proposed. Crew comfort during use is also an important design goal.
- A mask-delivered, oxygen re-breather system with carbon dioxide removal suitable for use in space flight Decompression Sickness therapy. Flow rates of at least 10 L/minute are needed. Proposal should include an

oxygen concentrator for use in ambient air. Overall system mass, including consumables, is extremely important.

- A software system that can take physiological monitoring data and use it to allow a non-physician crewmember, with very limited medical training, to provide an individually tailored, hyperbaric therapy regimen. Available physiological signals may be assumed to include non-invasive oximetry for blood Oxygen saturation, ECG, respiratory rate, and Carbon Dioxide concentration in exhaled air.

B3.07 Food and Galley
Lead Center: JSC
Participating Center(s): None

As NASA begins to look beyond low Earth orbit and to plan for future exploration missions, such as to the Moon or Mars, new technologies in food science and food processing will be needed. The impossibility of regularly resupplying a Mars crew, for example, means that a complete diet for 6 crewmembers for more than 3 years will have to be carried with them. Because of the mass of refrigeration equipment, freezing a large quantity of food may not be a practical solution. As the crew remains on the lunar or planetary surface, crops will be grown to supplement the crew's diet, especially within the context of experimental advanced life support systems that use plants to revitalize the air and water supply. Hence, methods for processing potential food crops are needed. Areas in which innovations are solicited are:

Ultra-long Duration, Shelf-Stable Food
An initial trip to Mars, for example, will require a stored food system that is nutritious, palatable and provides a sufficient variety of foods to support significant crew activities on a mission of at least 3 years duration.

Development of highly acceptable, shelf stable food items that use high quality ingredients is important to maintaining a healthy diet. Food items developed should be an important component of a healthy diet, low in sodium, and should contain less than 35% of calories from fat. Shelf life potential in the 3 – 5 years range is needed. Shelf life extension may be attained through new food preservation methods and/or packaging.

Advanced Packaging
The current food packaging used on Shuttle and the International Space Station is not biodegradable or recyclable, and thus represents a significant trash management problem for exploration class missions. Waste packaging in Shuttle missions is returned to Earth for disposal and packaging waste for International Space Station is incinerated upon reentry into Earth's atmosphere. New packaging technology is needed to minimize waste from packaged food. An example might be a biodegradable package that can withstand the retort process or a plastic or other packaging material that can readily be recycled to make objects of value to the space flight mission.

Food Processing Equipment
Advanced life support systems, which use chemical, physical and biological processes, are being developed to support future human planetary exploration. One such system might grow crops hydroponically and then process them into edible food ingredients or table ready products. Equipment to process crops in space should be highly automated, highly reliable, safe, and should minimize crew time, power, water, mass, and volume. Equipment for processing raw materials must be suitable for use in hypo-gravity (e.g., 3/8th-g on Mars) and in hermetically sealed habitats. Some potential crops for advanced life support systems include wheat, soybeans, white potatoes, sweet potatoes, peanuts, and rice. Examples of space flight compatible, food processing equipment include:

- Pressing the oil out of peanuts using an aqueous extraction method.
- Producing a nutritive sweetener source from high carbohydrate baseline crops (e.g., potatoes, sweet potatoes).
- Developing equipment that produces food products from rice, potatoes, soybeans, etc.
- A bread machine that has adjustable speeds and rising/baking times.
- Sanitizing salad crops through a highly automated process.

B3.08 Biomedical Research and Development of Noninvasive, Unobtrusive Medical Devices for Future Flight Crews
Lead Center: GRC
Participating Center(s): None

Human presence in space requires an understanding of the effects of the space environment on the physiological systems of the body. The objective of this subtopic is to sponsor fundamental and applied research leading to the development of noninvasive, unobtrusive medical devices that will mitigate crew health, safety, and performance risks during future flight missions. Medical diagnostic and monitoring devices are critical for providing health care and medical intervention during missions, particularly those of extended duration. Of particular interest are devices with minimized mass, volume, and power consumption, and capable of multiple functions. Design enhancements that improve the operation, design reliability, and maintainability of medical devices in the space environment are also sought. Of additional consideration are innovative instrumentation automation, ease of usage, improved astronaut (patient) comfort, and easy-to-read information displays.

Major research disciplines include: endocrinology, immunology, hematology, microbiology, muscle physiology, pharmacology, drug delivery systems, and mechanistic changes in neurovestibular, cardiovascular, and pulmonary physiology.

Innovations in the following areas are sought:

- Biomedical monitoring, sensing, and analysis (including the acquisition, processing, communication, and display) of electrical, physical, or chemical aspects of a human's health or physiologic state.
- Instrumentation to be used for in-flight and ground-based studies for reliable and accurate noninvasive monitoring of human physiological functions such as the cardiovascular, musculoskeletal, neurological, gastrointestinal, pulmonary, immunological, and hematological systems.
- Noninvasive, biosensors for real-time monitoring of blood and urine chemistry including, gases, calcium ions, electrolytes, cellular components, proteins, lipids, and hormones.
- In-flight specimen analysis to evaluate physiological, metabolic, and pharmacological responses of astronauts.
- Instrumentation to maintain and assess levels of aerobic and anaerobic physical capability.
- Instrumentation to monitor physical activity and loads placed on different segments of the human body.
- Instrumentation to provide quantitative data to establish the effectiveness of an exercise regimen in ground-based research, and to measure bone strain in the hip, heel, and lumbar spine during exercise.
- Assessment of gas bubble formation or growth in the body after in-flight or ground-based decompression, and to prevent or minimize associated decompression sickness In-flight assessment of the metabolism of proteins, carbohydrates, lipids, vitamins, and minerals.
- Smart sensors capable of sensor data processing and sensor reconfiguration.
- Small, portable, medical imaging diagnostic instrumentation.
- Virtual medical instrumentation.

B3.09 Radiation Shielding to Protect Humans
Lead Center: LaRC
Participating Center(s): JSC

Revolutionary advances in radiation shielding technology are needed to protect humans from the hazards of space radiation during NASA missions. All space radiation environments in which humans may travel in the foreseeable future are considered, including low-Earth orbit, geosynchronous orbit, Moon, Mars, etc. All radiations are considered, including particulate radiation (electrons, protons, neutrons, alpha, light to heavy ions with particular emphasis on ions up to iron, mesons, etc.) and including electromagnetic radiation (ultraviolet, x-rays, gamma rays, etc.). Technologies of specific interest include but are not limited to the following:

- Advanced computer codes are needed to model and predict the transport of radiation through materials.
- Advanced computer codes are needed to model and predict the effects of radiation on the physiological performance, health, and well being of humans in space radiation environments.

- Innovative, lightweight radiation shielding materials are needed to shield humans in aerospace transportation vehicles, large space structures such as space stations, orbiters, landers, rovers, habitats, space suits, etc. The materials emphasis should be on non-parasitic radiation shielding materials, or multifunctional materials, where one of the functions is the radiation shielding function.
- Non-materials and "out-of-the-box" radiation shielding technologies are also of interest.
- Laboratory and space flight data are needed to validate the accuracy of radiation transport codes.
- Laboratory and space flight data are needed to validate the radiation shielding effectiveness of radiation shielding materials and non-materials solutions.
- Comprehensive radiation shielding databases and design tools are also sought to enable designers to incorporate and optimize radiation shielding into space systems during the initial design phases.
- Accurate and reliable theoretical and phenomenological models are needed for the collision of radiation ions to generate the input databases for transport phenomena. The models that give comprehensive results in a fast manner for broader (preferably whole) ranges of colliding ions, for ion energies from a few MeV to a few GeV, are desirable. The information needed is as follows:
  - Total, elastic, absorption, and fragmentation cross sections; spectral and angular distributions of producing particles;
  - Multiparticle fragmentations;
  - Cluster effects; and
  - Meson production.

B3.10 Biomass Production for Planetary Missions
Lead Center: KSC
Participating Center(s): JSC

The production of Biomass (in the form of edible food crops) in closed or nearly closed environments is essential for the future of long term planetary exploration and human settlement. These technologies will lead not only to food production but also to the reclamation of water, purification of air, and recovery of inedible plant resources. Areas in which innovations are solicited include the following:

Crop Lighting
- Sources for plant lighting such as, but not limited to, high-efficiency lamps or solar collectors
- Transmission and distribution systems for plant lighting including, but not limited to, luminaires, light pipes and fiber optics
- Heat removal techniques for the plant growth lighting such as, but not limited to, water-jackets, water barriers, and wavelength-specific filters and reflectors

Water and nutrient delivery systems
- Technologies for production of crops using hydroponics or solid substrates
- Water and nutrient management systems
- Regenerable media for seed germination plant support
- Separation and recovery of usable minerals from wastewater and solid waste products for use as a source of mineral nutrients for plant growth

Mechanization and Automation
This system development includes innovations in propagation, seeding, and plant biomass processing. Plant biomass processing includes harvesting, separation of inedibles from edibles, cleaning and storage of edibles (seed, vegetable, and tubers) and removal of inedibles for resource recovery processing.

Facility or System Sanitation
This includes technologies to prevent excessive build-up of microorganisms within nutrient delivery systems.

Health Measurement
Remote, direct and indirect methods of measuring plant health and development using canopy (leaf) spectral signatures or fluorescence to quantify parameters such as rate of photosynthesis, transpiration, respiration, and nutrient

uptake. Data acquisition should be non-invasive or remotely sensed using spectral, spatial, and image analysis. System modeling and decision-making algorithms may be included.

Sensor Technologies
Innovations are required for development of sensors using miniature, subminiature and microtechnologies for evaluation of all phases of biomass production. Such sensor arrays include wide ranging applications of gas and liquid sensors as well as photo sensors and microbiological community indicators. Innovations are required in all phases of sensor development including biomass fouling, miniaturization, wireless transmission, multiple phase and multiple tasking sensors and interface with AI data collection systems.

Flight Equipment Support
Innovative hardware and components developed to support research in the Space Shuttle and onboard the International Space Station. Biomass production investigations using flight support equipment will be required to meet the demanding requirements for space flight operations, meet the rigorous scientific data collection standards, and produce plants in a controlled environment for research purposes and food. Innovations in whole package design and in component designs will be required.

B4 Research Integration

The BPR Enterprise seeks to use its research activities to encourage educational excellence and to improve scientific literacy from primary school through the university level and beyond. The Enterprise delivers value to the American people by facilitating access to the experience and excitement of space research. NASA seeks to engage the commercial sector in exploiting the economic benefits of space. We also strive to involve society as a whole in the transformations that will be brought about by research in space.

B4.01 Telescience and Outreach for Space Exploration
Lead Center: MSFC
Participating Center(s): JSC

NASA wants to provide to the general public, schools and industry, access to space and microgravity, and to information about the commercial investigations and results.

Telescience
There are many potential users for NASA services and data located throughout the U.S. There are three general types of users for NASA activities. The first type is the principal investigator (PI) who is responsible for the spacecraft, experiment and attendant science and commands the payload or experiment. The second type is the secondary investigator(s) who participates in analysis of the science and its control but does not send commands. The third type is the educational user from graduate students to secondary school students. These users will receive either data processed by the PI or unprocessed data. Commercial investigations require the ability to receive, process and display telemetry, view video from science sources, including the ISS, and talk to NASA about the science and operations. To conduct or be involved in general science activities, including the ISS science operations, a user will require various services from the Payload Operations Integration Center (POIC) located in Huntsville, Alabama, or other control centers located at various NASA facilities. These services are required to enable the experiment to be controlled using the inputs from various video sources, telemetry and the crew. Inputs allow the experimenter to send to their spacecraft or experiment commands to change various experiment operations. Before an experiment can get underway, an experimenter must participate in the payload planning process to schedule on-board services like electricity, crew time and cryogenics. This planning process is integral to the entire payload operation and requires the PI or his representatives to participate via voice or video teleconferencing. To enable users to operate from their home base, whether it is located at a laboratory, office or home, these services (commensurate to the level of their operation) must be provided at their location at a reasonable cost. Costs include both the platform upon which these services will run and the communications required to provide these services to the experimenter's location.

Outreach and Education
Another user is the general public observer who is interested in the science that is being conducted. Proposals are sought which provide a system or systems based on commercial solutions. These systems should allow outreach participation in NASA commercial programs, including the science and operational levels. The public should receive data, including voice, video and processed data, but generally would not be allowed to interact with the current investigations. Systems could provide for the general public access to NASA and commercial science activities and operations through low-cost technologies, and outreach and education activities. The systems should be capable of facilitating secondary and college-level students' access to and the ability to participate in science activities.

Similarly, the systems should be able to accommodate institutions and organizations which promote the use of science and technologies, e.g., museums and space camps.

B4.02 Space Commercialization
Lead Center: MSFC
Participating Center(s): None

In accordance with the Space Act, as amended, to "seek and encourage to the maximum extent possible the fullest commercial use of space," NASA facilitates the use of space and microgravity for commercial products and services. The products may utilize information from in-space activities to enhance an Earth-based effort, or may require in-space manufacturing. This subtopic's goal is the development of infrastructure equipment for commercial experimentation and operations in space, or the transfer of these technologies to industry in space or on Earth. Automated processes and hardware (robotics) which will reduce crew time are a priority. All Agency activity in microgravity, including those in life science and microgravity sciences, which lead to commercial products and services, are of interest. Some specific areas for which proposals are sought include:

Biotechnology and Agribusiness
Biotechnology, biomedical and agricultural instrumentation or techniques that exploit space-derived capabilities or data to support the commercial development of space by the agricultural, medical or pharmaceutical industry. This includes, in particular:

- Portable Biological Sensors -The need for sensing devices that can detect and identify biological pathogens (airborne or in vivo) is desired to support NASA's mission for a permanent presence of man in space.
- Development of Noninvasive Health Monitoring Systems/models - Application to NASA's crew health program for extended duration missions. For example, (1) novel in vitro cell-matrix models for studying the effects of microgravity on human tissue repair and wound healing, (2) novel organotypic skin models which simulate physiological changes found in humans under a microgravity environment, (3) functional models for delineating the MG-inducible or MG-responsive pathways of human tissue angiogenesis (new blood vessel formation).
- Physiological measurement in microgravity of bone growth and the immune system in microgravity.
- Technology for innovative research in plant-derived pharmaceuticals using microgravity.
- Instrumentation for agricultural research, i.e., genetic manipulation of plants using microgravity.
- Instrumentation or technology to explore the use of microgravity in genetic assay, analysis, and manipulation.
- Instrumentation to analyze cell reactor systems and characterize cell structure in microgravity in order to develop enhanced drug therapies that can also be applied to pharmaceutical development and commercialization.
- Innovative techniques for dynamic control and cryogenic preservation of protein crystals.
- Instrumentation for preparation of protein crystals for x-ray diffraction experiments without the use of frangible materials.
- Low temperature control chambers requiring little or no power for bringing temperature sensitive experiments up to or back from the International Space Station.

Microgravity Payloads
- Design/develop microgravity payloads for space station applications that lead to commercial products or services.
- Enabling commercial technologies that promote the human exploration and development of space.
- Enabling commercial technologies through the use of ISS as a commercial test bed for hardware, products, or processes.

- Enabling technology designed to reduce crew workloads and/or facilitate commercial investigations or processing through automation, robotics, or nanotechnology.

Combustion Science
Innovative applications in combustion research that will lead to commercial products or improved processes through the unique properties of space or through enhanced or innovative techniques on the ground.

Food Technology
Innovative applications of space research in food technology that will lead to developing commercial food products or improved food processes through the unique properties of space or through enhanced or innovative techniques on the ground.

Biomedical Materials
Innovative unique structure materials where microgravity promotes structures such as biodegradable polymers for use in wound healing and orthopedic applications.

Entertainment Value Missions
Technology for innovative approaches for commercial economic benefit from space research involving broadcasting, e-business or other activities that have entertainment value.

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8.1.3 EARTH SCIENCE

NASA's Earth Science Enterprise uses satellites and other tools to intensively study the Earth in an effort to expand our understanding of how natural processes affect us, and how we might be affecting them. Such studies will yield improved weather forecasts, tools for managing agriculture and forests, information for fishermen and local planners, and, eventually, the ability to predict how the climate will change in the future. Earth Science has three main components: a series of Earth-observing satellites, an advanced data system, and teams of scientists who will study the data. Key areas of study include clouds; water and energy cycles; oceans; the chemistry of the atmosphere; land surface; water and ecosystem processes; glaciers and polar ice sheets; and the solid Earth. Working together with the nations of the world, Earth Science seeks to improve our knowledge of the Earth and to use that knowledge to the benefit of all humanity.

http://earth.nasa.gov

E1 Instruments for Earth Science Measurements

NASA's Earth Science Enterprise is studying how our global environment is changing. Using the unique perspective available from space and airborne platforms, NASA is observing, documenting, and assessing large-scale environmental processes, with emphasis on biology and biogeochemistry of ecosystems and the global carbon cycle, global water and energy cycle, climate variability and prediction, atmospheric chemistry, and solid Earth and natural hazards. A major objective of the ESE instrument development programs is to implement science measurement capabilities with small or more affordable spacecraft so that the development programs can meet multiple mission needs and therefore make the best use of limited resources. The rapid development of small, low cost remote sensing and in situ instruments is essential to achieving this objective. Consequently, the objective of the Instruments for Earth Science Measurements SBIR topic is to develop and demonstrate instrument component and subsystem technologies which reduce the risk, cost, size, and development time of Earth observing instruments, and enable new Earth observation measurements. The following subtopics are concomitant with this objective and are organized by measurement technique.

E1.01 Passive Optical
Lead Center: LaRC
Participating Center(s): ARC, GSFC

Proposals are sought for the development of innovative technology for measuring the atmosphere and Earth surface using passive optical techniques. The innovations are intended to increase our understanding of the interacting physical, chemical and biological processes that form the complex Earth system.

Atmospheric measurements of interest include climate and meteorological parameters, such as temperature, amounts of aerosols, clouds, water vapor, carbon dioxide and methane; and, chemical constituents such as ozone, nitrogen dioxide, nitric oxide, carbon monoxide, and hydrocarbons. Surface measurements of interest include vegetation index, multi-spectral imaging, bi-directional reflectance, biological productivity, surface terrain mapping, temperatures of water, land and ice, ocean productivity and ocean color. Technology innovations may include components, subsystems, and complete systems and should address reduced size, weight or power, improved reliability and lower cost. The wavelengths of interest include IR, visible and ultraviolet bands. The innovations should expand the capabilities of airborne systems (manned and unmanned) and the next generation spaceborne systems. Innovative approaches are an important element of competitive proposals under this solicitation. Specific needs include:

System Architectures

- Innovative instrument architectures that provide flexibility in system configuration to address specific measurement requirements. For example, sampling flexibility in either the spectral or spatial domain of an imaging spectrometer focal plane array will provide the ability to trade between spectral and spatial resolution in the context of a specific scientific problem as constrained by limited downlink bandwidth.
- Innovative instrument architectures that expand scientific knowledge and provide significant reductions in the end-to-end implementation. This includes designs and component technologies relating to improved sensors for observations Earth's surface and atmosphere. Examples of instruments include multi-spectral imaging radiometers and flux radiometers for wavelengths from the UV to microwave. Innovative measurement concepts or advances leading to smaller and lower cost instruments will be considered. Technical approaches should include application of un-cooled infrared detectors, non-mechanical choppers, calibration methods and tuned filters.
- High throughput compact systems (f/1-f/2).
- Wide field of view spectrometer systems (e.g., with expandable architectures) with no moving parts.
- Systems with inherent environmental stability.

Component Technologies

- Optical technologies that will enable high spatial resolution (< 10 meter) measurements along track for spacecraft sensors in low Earth orbit. Combinations of high light collection efficiency and instrument throughput, and fast, low noise detector readout are required to provide adequate signal power (SNR > 500) to address multi- and hyper-spectral measurement requirements.

- Wedge filters suitable for space application and capable of spectral resolutions of a few nano-meters over the visible through short-wave IR portions of the spectrum, and angular (IFOV) resolutions on the order of a milli-radian.
- 4 K x 4 K and larger detector arrays sensitive in near UV (300-400 nm) and Near IR (1-3 micron) with large (> 1 million electrons) well depth.
- Ultra-stable spectral calibration techniques for data quality management and the evaluation of long-term sensor degradation trends in space instruments.
- On-board, near real-time processing for atmospheric correction, geo-location, and geometric correction of digital image data.
- Optical imager technologies that will enable lightweight, low cost large aperture optical systems optics for a variety of land, ocean, and atmospheric observations through the elimination of conventional telescopes and focal planes in space based imagers. For example, phased arrays or multi-spectral imagers based on holographic and/or diffractive optics. Instruments should have performance specifications comparable to or better than current imagers such as MODIS aboard NASA's Terra satellite.
- Fast, 1-meter diameter lightweight telescope for space application with minimal distortion in the 0.3- 3-micron wavelength range.
- Ultra-stable remote sensor calibration techniques for long-term trend determination in space instruments.
- Development of innovative techniques and component technologies for measuring polarization of light scattered from the atmosphere.
- Advanced gratings on flat or curved surfaces that maximize efficiency and minimize scatter and ghosts.
- Linear variable filters with extended range, seamlessly stitched filter strips.
- Broadband antireflection methods that can be applied to the photodetector array, in the visible and infrared.
- Novel or improved high-resolution dispersive elements.
- Environmentally robust, electronically variable filters with extended spectral range.

Innovative Optomechanical Designs

- Development of systems capable of off-nadir pointing for the acquisition of multi-angle data, the acquisition of stereo pairs, the frequent imaging of rapidly changing events from orbit scanning and tilting to remove sun reflection off the ocean, and the frequent imaging of rapidly changing events from orbit. Very low mass, power and high speed and flexibility are desired.
- Compact, lightweight optical designs that utilize a minimum number of optical surfaces.
- Non-classical designs utilizing guided wave optics.
- Self-aligning systems or methods of assembly.

E1.02 Active Optical
Lead Center: LaRC
Participating Center(s): JPL, GSFC

Innovative developments are needed in lidar technology for the remote measurement of atmospheric aerosols, clouds, molecular species (ozone, water vapor, carbon monoxide, carbon dioxide, methane, and nitrous oxide), meteorological parameters (density, pressure, temperature, and wind profiles), planetary surface topography, vegetation, and sub-surface ocean layers; for ground-based lidar systems and laser ranging systems that measure atmospheric backscatter, vegetation structure and composition, and pulse time-of-flight to laser transponders or reflectors on satellites. Specifically, technologies for expanding the measurement capabilities of current airborne lidar systems and for the next generation of spaceborne and Unmanned Aeronautical Vehicle (UAV) lidar systems are sought. Technology innovations may include lidar components, subsystems, and complete systems and may address reduced weight or power or increased energy efficiency, reliability, or autonomous operation.

Atmospheric Constituent Measurements

- Solid-state laser technology for tunable and/or fixed frequency, high-energy (> 500 mJ at more than 10 Hz) pulsed lasers for spaceborne applications. This includes solid-state laser materials compatible with diode pumping and high efficiency (> 2.5 percent wallplug) and new or improved optical materials for high efficiency frequency conversion. Of prime interest are long-lifetime, low weight and volume materials and technologies applicable to highly efficient, conductively cooled lasers operating in the 0.28-0.36, 0.47-0.54, 0.7-1.1, and 1.5-2.8 micron regions; also interested in the 3.2-4.7 micron region. Also needed are single-mode, linenarrowed, compact sources for injection seeding in the 0.28-0.36, 0.7-1.1 and 1.5-2.1 micron regions and high reliability, high efficiency, high brightness, conductively cooled diode arrays operating in wavelength regions for pumping solid-state lasers.

- Lidar receiver technology for large (> 3m^2), lightweight collection apertures having multiple-wavelength operation from UV to near IR is needed. Inherent spectral selection/dispersion and high peak transmission (50-80 percent), electromagnetically tuned, narrow bandwidth (10-100 pico-meters) filtering is desirable. Small- and large-angle scanning (up to 3 degrees and 30-60 degrees off nadir, respectively) of 0.5 meter and 1.0 meter lidar systems is needed for space. Low mass and few to no moving parts.
- Signal detection and processing subsystems with quick recovery (less than 3 microseconds) from saturation and high-speed, high-quantum efficiency (30-80 percent) detectors with low-noise and good linearity are needed for lidar operation over large dynamic ranges.
- For UAV applications, compact, high repetition rate, narrow line-width laser transmitter systems are needed that produce energies from micro- to milli-Joules per pulse. Laser energies of more than 100 mJ at 30-1000 Hz in the UV and more than 200 mJ at 10-20 Hz in the 355, 936, 944, and 1064 nm region are needed.
- High CW power (> 500 mW-1 W) single spatial mode laser diodes, based on simplistic structures such as the Fabry-Perot cavity, for core-pumping of fiber lasers. Wavelength regions mainly include 800-810 nm, but also of interest are 780-785 nm, and 980 nm.
- Single-element and array detectors, combined with preamplifier circuitry in a single integrated circuit, for lidar detection at 355nm, 532nm, and 1064nm having several giga-hertz bandwidth, high quantum efficiencies, good linearity, and minimum cooling requirements.
- Optical phased array scanning concepts for programmable beam pointing with high transmission (> 90 percent) and angular deflection capability > 20 degrees. Aperture diameters from 2 cm to 1 m are of interest and preservation of beam quality is a primary requirement.
- Large aperture, ultra light, scanning lidar receivers with high efficiency, narrow field-of-view, and narrowband filtering.
- Scanning lidar transceivers that use aperture sharing and are capable of producing multiple look angles, each with a small field-of-view.

Coherent Wind Measurements in the 1.5-2.5 Micrometer Wavelength Range

- Low mass, compact optics for deflecting a circularly polarized laser beam for a conical scan. Diameters of 5 cm to 1 m with an immediate need of up to 50 cm. Preservation of laser beam quality is required.
- Low mass, 1-m class beam expanding telescope technology with low fabrication cost and long-lived performance in space environment.
- Technology for autonomous operation and alignment maintenance of coherent lidar systems; such as a low-mass, low-power, low-voltage optical element capable of correcting piston, defocus, astigmatism, coma, and spherical aberrations.
- Integrated opto-electronic receiver combining photodetectors, local oscillator laser, beam conditioning and combining, and signal processing components.
- Fast (few tens of microseconds) lag-angle compensation optics technology for precise, reliable steering of the optical axis of a space-based Doppler lidar.
- Single-element and array detectors having high bandwidth, high quantum efficiencies in the 1.5-2.5 micron wavelength band. Bandwidths up to 6 GHz are desired.
- Pulsed, eye safe laser technology having technical path leading to simultaneous characteristics of > 2J energy, > 12 Hz PRF, < 500 W laser power requirement when pulsing, < 2 microsecond duration, < 1 m/s equivalent pulse spectrum, < 1.3 M^2 beam quality, intermittent operation with periods of 1-10 minutes and duty cycle around 20 percent and minimum "off" power draw and minimum time to restabilize, and which shows potential for 7-year lifetime in space environment.
- Diode-laser arrays operating near 0.79 micrometers having pulse lengths > 1.0 ms, energy densities > 1.3 J/cm^2, duty cycle > 0.20 and narrow beam divergence.
- High efficiency methods for concentrating the emissions from nominal 1.0 cm square arrays to 4.0 mm diameter spot sizes.
- Tunable single-mode semiconductor lasers or other compact, single frequency sources for use as injection seeders and/or local oscillators, with linewidths 0.1-0.2 MHz operating in the 1.8-2.2 micron and 3.0-3.5 micron regions.

Surface Topography and Oceanic Measurements

- Compact, conductively-cooled, near-infrared laser transmitters with less than 1 nsec pulses, single spatial mode, several milli-joule performance at multi-kilohertz pulse rates.
- Oceanic LIDAR systems or components in the 480-685 nm wavelength region for remote sensing of sub-surface ocean layers and fluorescence.
- Quadrant Geiger-mode avalanche, photo diodes or comparable micro-channel plate photomultipliers with a quantum efficiency approaching 40 percent @ 532 nm, less than or equal to 400 psec risetime, and submicro-second gating at 2 kHz rates.
- Silicon avalanche photo diodes, photodiode arrays, and photon counting detectors with quantum efficiency greater than 35 percent at 1064 nm wavelength; and high efficiency, high speed, and low noise detectors for the 1500 to 2200 nm wavelength region.
- Signal detection and processing subsystems with quick recovery (less than 30 micro-sec) from saturation and high-speed, high-quantum efficiency (30-80 percent) detectors with low noise and good linearity are needed for lidar operation over large dynamic ranges.

Direct Detection and Other Measurements

- Laser techniques and component technology for measurement of the wind field and wind shear using direct-detection methods, with high accuracy and high range resolution. Eye safety is a consideration.
- High spectral resolution filters with high throughput, out of band spectral blocking, frequency tunable, and frequency stabilization for direct-detection measurements of winds at 355 nm (1 GHz bandwidth) and 1064 nm (100 MHz bandwidth).
- Compact, power efficient, frequency reference with better than 1 part in 10^14 stability and accuracy; that is suitable for interplanetary missions.
- Adaptive photon-counting correlation range receivers capable of extracting satellite range data with high time resolution (better than 20 psec) during daylight operations.
- High detectivity, spectrally diverse receivers including narrowband notch filters, high transmission narrow bandpass optical filters, and multi-channel array detection.

E1.03 In Situ Terrestrial Sensors
Lead Center: GSFC
Participating Center(s): ARC, JPL

Proposals are sought for the development of in situ measurement systems that will enhance the scientific and commercial utility of data products from the Earth Science Enterprise program and that will enable the development of new products of interest to commercial and governmental entities around the world. Technologies of interest include:

- Autonomous GPS-located ocean platforms to measure and transmit to remote terminals upper ocean and lower atmosphere properties including temperature, salinity, momentum, light, precipitation, and biology. Similar sensor packages for use onboard ships while under way.
- Autonomous low-cost systems to measure surface and lower atmospheric parameters including soil moisture, precipitation, temperature, wind speed and humidity.
- Small, lightweight instruments suitable for balloons, kites, or small remotely piloted aircraft for in situ measurements of atmospheric trace gasses and cloud radioactive properties including extinction, absorption, scattering phase function and phase function asymmetry.
- Wide-band microwave radiometers capable of high-speed characterization of cloud parameters, including liquid and ice phase precipitation, that can operate in harsh environmental conditions (e.g., on-board ships and aircraft).
- Autonomous GPS-located airborne sensors that remotely sense atmospheric wind profiles in the troposphere and lower stratosphere with high spatial resolution and accuracy.
- Systems and devices for measurement of atmospheric aerosol chemical, microphysical, and radioactive properties. Autonomy is desired for ground-station network applications and deployment aboard aircraft.
- Lightning location techniques to locate VLF sferic sources (5 to 15 kHz) within 100 km at ranges of 2000 km or more.

- Systems for in situ measurement of atmospheric electrical parameters including electric and magnetic fields, conductivity, and optical emissions.
- Systems to measure line- and area-averaged rain rate at the surface over lines of at least 100 meters and areas of at least 100x100 meters.
- Lightweight, low-power systems that integrate the functions of inertial navigation systems and GPS receivers for characterizing the flight path of remotely piloted vehicles.
- Low-cost, stable (< 1 percent over several months) portable radiometric sources for field characterization of spectral radiometers.
- Innovative approaches for the gathering, storing, and forwarding of in situ measurements using common carrier infrastructures.
- Mass spectrometer time-of-flight system with: (1) weight < 1kg, (2) dynamic range > 1E8, (3) a mass range of 1 - 2000 amu with unit resolution throughout, and (4) innovative ionization techniques with an order of magnitude improvement over current sources.

E1.04 Passive Microwave
Lead Center: GSFC
Participating Center(s): JPL

Proposals are sought for the development of innovative passive microwave technology in support of Earth System Science measurements of the Earth's atmosphere and surface. These microwave radiometry technology innovations are intended for use in the microwave frequency band from, principally about 1 to 300 GHz, but also with applications outside that band. The key science goal is to increase our understanding of the interacting physical, chemical and biological processes that form the complex Earth system. Atmospheric measurements of interest include climate and meteorological parameters, including temperature, water vapor, clouds, precipitation, aerosols; air pollution; and chemical constituents such as ozone, NOX, and carbon monoxide. Earth surface measurements of interest include water, land and ice surface temperatures, land surface moisture, snow coverage and water content, sea surface salinity and winds, and multi-spectral imaging.

Technology innovations are sought that will provide the concepts, components, subsystems, or complete systems to improve Earth System Science measurements. Technology innovations should address enhanced measurement capabilities such as improved spatial or temporal resolution, spectral resolution, or calibration accuracy. Technology innovations should provide reduced size, weight, power, improved reliability and lower cost. The innovations should expand the capabilities of airborne systems (manned and unmanned) as well as next generation spaceborne systems. Highly innovative approaches that open new pathways are an important element of competitive proposals under this solicitation. Specific technology needs include:

- Imaging radiometers, receivers or receiver arrays on a chip, and flux radiometers for microwave wavelengths (1 - 500 GHz).
- Large aperture, deployable antenna systems suitable for highly reliable space deployment with RMS surface accuracy of ~ 1/50th wavelength. Such large apertures can be real or synthetic apertures. Of key importance is the ability for a highly compact launch configuration, followed by a highly reliable erection and resultant surface configuration. Novel approaches to beam steering for these very large aperture antenna systems are also desired.
- Onboard data processing capabilities that enable real-time, re-configurable computational approaches that enhance research flexibility. Such approaches should improve image reconstruction, enable high compression ratios; improve atmospheric corrections and the geo-location and geometric correction of digital image data.
- Techniques for the detection and removal of Radio Frequency Interference (RFI) in microwave radiometers are desired. Microwave radiometer measurements can be contaminated by RFI that is within or near the reception band of the radiometer. Electronic design approaches and subsystems are desired that can be incorporated into microwave radiometers to detect and suppress RFI, thus insuring higher data quality.
- New technology calibration reference sources for microwave radiometers that provide greatly improved reference measurement accuracy. High emissivity (near block-body) surfaces are often used as on-board calibration targets for many microwave radiometers. NASA seeks ways to significantly reduce the weight of aluminum core target designs, while reliably improving the uniformity and knowledge of the calibration target temperature. NASA seeks innovative new designs for highly stable noise-diode or other electronic devices as additional

reference sources for on-board calibration. Of particular interest are variable correlated noise sources for calibrating correlation-type receivers used in aperture synthesis and polarimetric radiometers.

- New approaches, concepts and techniques are sought for microwave radiometer system calibration over or within the 1 -300 GHz frequency band, that provide end-to-end calibration to better than 0.1°K, including corrections for temperature changes and other potential sources of instrumental measurement drift and error.
- Focal plane array modules for large-aperture passive microwave imaging applications.
- High power (> 5 mW) signal sources and low noise (< 500 K) heterodyne receivers for operation above 100 GHz.
- Multi-GHz. Low power, 4-bit under-sampling analog-to-digital converters and associated digital signal processing logic circuits.
- Low power lightweight microwave radiometers are desired that are able to operate stably over long periods, with DC power consumption of less than 2 W and preferably less than 1 W, not including any mechanisms.
- MMIC LNA for spaceborne microwave radiometers, covering the frequency range of 165 to 193 GHz, having a noise figure of 6.0 dB or better (and with low 1/f noise).
- NASA is developing satellite systems that will use passive and active microwave sensing at L-band and other frequencies to measure sea surface salinity, and soil moisture to a depth of ~ 10 cm. In support of these global research efforts, the following ancillary measurement systems are required:
  - Inexpensive approaches to ground sensors are desired that are capable of measuring areas at least 100,000 km^2, with spatial resolution of 20 km. These ground sensors will be needed to validate those space-borne measurements. Measurement of ground-wave propagation characteristics of radio signals from commercial sources may satisfy that need. Although absolute values of soil moisture are desirable, they are not required if the technique can be calibrated frequently at suitable sites. Cost per covered area, autonomous operation, anticipated accuracy and depth resolution of the soil moisture measurement will be considerations for selection.
  - Autonomous GPS-located ocean platforms are needed that can measure upper ocean and lower atmosphere properties including temperature, salinity, momentum, light, precipitation, and biology, and can communicate the resultant data and computational or configuration instructions to and from remote terminals. Similar sensor packages are desired for use onboard ships while under way. This includes the development of intelligent platforms that can change measurement strategy upon receipt of a message from a command center.
  - Autonomous low-cost systems are desired that can measure Earth and ocean surface and lower atmospheric parameters including soil moisture, precipitation, temperature, wind speed, sea surface salinity, surface irradiance and humidity.

E1.05 Active Microwave
Lead Center: JPL
Participating Center(s): GSFC

Active microwave sensors have proven to be ideal instruments for many Earth science applications. Some examples include global freeze/thaw monitoring and soil moisture mapping, accurate global wind retrieval and snow inundation mapping, global 3-D mapping of rainfall and cloud systems, precise topographic mapping and natural hazard monitoring, global ocean topographic mapping and glacial ice mapping for climate change studies. For global coverage and the long-term study of Earth's eco-systems, space-based radar is of particular interest to Earth scientists. Radar instruments for Earth science measurements include Synthetic Aperture Radar (SAR), scatterometer, sounder, altimeter and atmospheric radar. The life-cycle cost of such radar missions has always been driven by the resources - power, mass, size, and data rate - required by the radar instrument, often making radar not cost competitive with other remote sensing instruments. Order-of-magnitude advancement in key sensor components will make the radar instrument more power efficient, much lighter in weight and smaller in stow volume, leading to substantial savings in overall mission life-cycle cost by requiring smaller and less expensive spacecraft buses and launch vehicles. On-board processing techniques will reduce data rates sufficiently to enable global coverage. High performance yet affordable radars will provide data products of better quality and deliver them to the users in a more timely and frequent manner with benefits for science, as well as civil and defense communities. Technologies which may lead to advances in instrument design, architectures, hardware, and algorithms are the focused areas of this subtopic. In order to increase the radar remote sensing user community, this subtopic will also consider radar data applications and post processing techniques.

The frequency and bandwidth of the operation are mission driven and defined by the science objectives. For SAR applications, the frequencies of interest include L-band (1.25 GHz), C-band (5.30 GHz), and X-band (9.6 GHz). The required bandwidth varies from 20 MHz to 300 MHz to achieve the desired resolution. The application of the synthetic aperture technique is also applied to other radars, including radar ice sounding and wide swath ocean altimeters. The sounder is a low frequency radar (< 100 MHz) with a very high percentage bandwidth (100 percent). The atmospheric radars operate at very high frequencies (35 GHz and 94 GHz) with only modest bandwidth requirements on the order of a few MHz. Ocean altimeters typically operate at L-band (1.2 GHz), C-band (5.3 GHz) and Ku-band (12 GHz).

The emphasis of this subtopic is on core technologies that will significantly reduce mission costs and increase performance and utility of future radar systems. Specific areas in which advances are needed include:

Synthetic Aperture Radar
- Lightweight, electronically steerable, dual-polarized, phased-array antennas
- Very large aperture antennas (50 m x 50 m) for geosynchronous SAR applications
- Shared aperture, multi-frequency antennas
- Lightweight deployable antenna structures and deployment mechanisms
- High-efficiency, high power, low-cost, lightweight, phase-stable transmit/receive modules
- Advanced transmit/receive module architectures such as optically fed T/R modules, signal up/down conversion within the module and novel RF and DC signal distribution techniques
- Advanced radar system architectures including flexible, broadband signal generation and direct digital conversion radar systems
- Advanced antenna array architectures including scalable, reconfigurable and autonomous antennas; sparse arrays; digital beamforming techniques; time domain techniques; phase correction techniques
- Innovative radar system concepts to achieve wide swath (> 250 km) to enable frequent site revisit and ultra-low-cost radars to enable constellations for global coverage
- Advanced radar component technologies including high-power low-loss RF switches, filters and phase shifters (MEMS devices are of particular interest); thin-film membrane compatible electronics, high-efficiency power converters; high-speed analog-to-digital converters; low-sidelobe chirp waveform generators and optical chirp generators
- Distributed digital beamforming and on-board processing technologies
- SAR data processing algorithms and data reduction techniques
- SAR data applications and post-processing techniques

Radar Ice-Sounder
- Synthetic aperture processing technique to increase resolution
- Lightweight broad-band (100 percent or more) low frequency (< 100 MHz), high gain (> 10 dB) deployable antennas
- Highly efficient, broadband, low frequency (< 100 MHz) transmitter
- Low-power, highly integrated radar components
- Data processing algorithms and data reduction techniques
- Hardware and/or software development for the ionospheric correction in space-borne radar sounders
- Data applications and post-processing techniques

Atmospheric Radar
- Low sidelobe, electronically steerable millimeter wave phased-array antennas and feed networks
- Low sidelobe, multi-frequency, multi-beam, shared aperture millimeter wave antennas
- Large (~300 wavelength), lightweight, low sidelobe, millimeter wave antenna reflectors and reflectarrays
- Lightweight deployable antenna structures and deployment mechanisms
- High power Ka-band and W-band transmitters (10 Kwatt)
- High-efficiency, low-cost, lightweight Ka-band and W-band transmit/receive modules
- Advanced transmit/receive module concepts such as optically fed T/R modules
- On-board (real-time) pulse compression and image processing hardware and/or software
- Advanced data processing techniques for real-time rain cell tracking, and rapid 3-D rain mapping

Polarimetric Ocean/Land Scatterometer

- Shared aperture, multi-frequency antennas
- Large, lightweight, electronically steerable reflectarrays
- Dual-polarized antennas with high polarization isolation
- Lightweight deployable antenna structures and deployment mechanisms
- High efficiency, high power, phase stable L-band, C-band and Ku-band transmitters
- Low-power, highly integrated radar components
- Calibration techniques, data processing algorithms and data reduction techniques
- Data applications and post-processing techniques

Wide Swath Ocean and Surface Water Monitoring Altimeters

- Shared aperture, multi-frequency antennas
- Large, lightweight antenna reflectors and reflectarrays
- Lightweight deployable antenna structures and deployment mechanisms
- High efficiency, high power, phase stable C-band and Ku-band transmitters
- Real-time on-board radar data processing
- Calibration techniques, data processing algorithms and data reduction techniques
- Data applications and post-processing techniques

Geosynchronous Ocean Altimeter

- Core radar technologies and signal processing definition

E1.06 Passive Infrared - Sub Millimeter
Lead Center: JPL
Participating Center(s): LaRC

Many NASA future Earth science remote sensing programs and missions require microwave- to submillimeter wavelength antennas, transmitters, and receivers operating in the 3-cm to 100-micron wavelength range (or a frequency range of 10 GHz to 3 THz). General requirements for these instruments include large-aperture (possibly deployable) antenna systems with rms surface accuracy of < 1/50th wavelength (or better); the ability to scan or image many beamwidths on the sky (array receivers); small low-power MMIC radiometers, and high-throughput, low power, backend correlators and spectrometers. The focus is on technology for passive radiometer systems that are more spectrally flexible, lighter, smaller, and use less power. These systems must be of durable design for use on aircraft platforms and at remote/autonomous observatory sites; they must also be suitable for space applications with lifetimes of 5 years or more. Earth remote sensing receivers typically operate at LN2 (or higher) temperatures and require moderate noise performance. Advances in cooler technology will enable use of technology presently used in astrophysics receivers, which are cooled to a few Kelvin for better sensitivity, requiring near quantum-noise-limited performance. For these systems, advancement is needed in primarily three areas: (1) the development of frequency-stabilized, broadband, tunable, fundamental local oscillator sources covering frequencies between 160 GHz and 3 THz; (2) the development of submillimeter-wave mixers in the 300-3000 GHz spectral region with improved sensitivity, stability, and IF bandwidth capability; and (3) the development of higher-frequency and higher-output-power MMIC circuits. Specific innovations are required in the following areas:

- Heterodyne system integration at the circuit and/or chip level is needed to extend monolithic microwave integrated circuit (MMIC) capability into the submillimeter regime. MMIC amplifier development for both power amplifiers and low noise amplifiers at frequencies up to several hundred GHz is solicited. Integration of a local oscillator multiplier chain, mixer, and intermediate frequency amplifier is one example. There is also a specific need to demonstrate radiometer systems using phased-arrays and MMIC radiometers from 60 GHz to approximately 400 GHz.
- Solid-state, phase-lockable local-oscillator sources with flight-qualifiable design approaches are needed with > 10 mW output power at 200 GHz and > 100 micro-watts at 1 THz; line widths should be < 100 kHz. Since heterodyne mixers are relatively broadband, a major limitation of existing local oscillator sources is a narrow tuning range, which requires many devices for the broad spectral coverage. For example, a single local-oscillator source that could tune from 1-2 THz with flat output power in excess of 10 micro-watts would find

immediate use. These local oscillator sources should be compact and have direct current power requirements < 20 W.

- Stable local-oscillator sources are needed for heterodyne receiver system laboratory testing and development.
- Multi-channel spectrometers that analyze intermediate frequency signal bandwidths as large as 10 GHz with a frequency resolution of < 1 MHz that are small and lightweight and that use low direct current power (< 5 mW per channel) with high stability.
- Compact and reliable millimeter and submillimeter instrumentation that produces high sensitivity images simultaneously in multiple spectral bands.
- Schottky mixers with high sensitivity at T = 100K and above.
- Superconducting HEB mixers and SIS mixers.
- Receivers utilizing planar diodes or alternative reliable technologies in the 300-3000 GHz spectrum.
- Lightweight and compact radiometer calibration references covering 100-800 GHz frequency range.
- Lightweight, field portable, compact radiometer calibration references covering frequencies up to 200 GHz. The reference must be temperature stable to within 1 Kelvin with a minimum of 3 temperature settings between 250 and 350 Kelvin.
- Low cost, special purpose, ground based receivers to detect signals radiated from active satellites that are in orbit for estimating rain rate, water vapor, and cloud liquid water.
- Large diameter (up to 25-m) deployable antennas suitable for Earth remote sensing at frequencies up to 30 GHz.
- Calibrated radiometer systems that can achieve accuracy and stability of 0.1K.

E1.07 Thermal Control for Instruments
Lead Center: GSFC
Participating Center(s): None

Future instruments for NASA's Earth Science Enterprises will require increasingly sophisticated thermal control technology. Optical alignment and sensor needs are requiring ever tighter temperature control, heat flux levels from lasers and other similar devices are increasing, and cryogenic applications are becoming more common. Some applications may require significantly increased power levels while others may require extremely low heat loss for extended periods. The advent of very small instruments may also drive the need for new technologies, particularly since such small instruments will have low thermal capacitance. In general, high performance, versatility, low cost, smaller mass and volume (down to the MEMS level), and high reliability are the prime technology drivers. Furthermore, the drive towards 'off-the-shelf' commercial spacecraft buses presents engineering and technological challenges for instruments. Innovative proposals for instrument thermal control systems are sought in the following areas:

- Miniaturized (down to the MEMS level), cryogenic (3K - 80K) heat transport devices, especially those suitable for cooling sensors and very small electronics.
- Advanced, multi-evaporator, two-phase heat transport devices to isothermalize very large structures such as antennas and telescopes.
- Highly reliable, miniaturized Loop Heat Pipes and Capillary Pumped Loops which allow multiple heat load sources and multiple sinks.
- Advanced thermoelectric coolers capable of providing 100s of milliwatts of cooling at 150 K and below.
- Hybrid cooling systems that make optimal use of radiative coolers.
- Advanced analytical techniques for thermal modeling, focusing on techniques that can be easily integrated with emerging mechanical and optical analytical tools.

E2 Platform Technologies for Earth Science

NASA is fostering innovations that support implementation of the Earth Science (ES) program, an integrated international enterprise to study the Earth system. ES uses the unique perspective available from orbit to study land cover and land use changes, short and long term climate variability, natural hazards, and environmental changes. Additionally, ES uses terrestrial and airborne measurements to complement those acquired from Earth orbit. ES has a parallel development effort to these platforms which include the largest ground and data system ever undertaken which will provide the facility for command and control of flight segments and for data processing, distribution, storage, and archival of vast amounts of ES research data. The ES Program defines Platforms as the host systems for ES Instruments. That is, they provide the infrastructure for an instrument or suite of instruments. Traditionally, the term 'platform' would be synonymous with 'spacecraft,' and it certainly does include spacecraft. However, 'platform' is intended to be much broader in application than spacecraft and is intended to include nontraditional hosts for sensors and instruments such as airborne platforms (piloted and unpiloted aircraft, balloons, drop sondes), terrestrial platforms, sea surface and subsurface platforms, and even surface penetrators. These application examples are given to illustrate the wide diversity of possibilities for acquiring ES data consistent with the future vision of the ES Program and indicate types of platforms for which technology development is required.

E2.01 Structures and Materials
Lead Center: LaRC
Participating Center(s): ARC, GSFC, JPL, JSC

Advanced materials and structures technologies are needed for future ES platforms. These include materials and multifunctional structures that enable significant weight reduction and that possess extended life in the space environment, novel structural concepts for deployment to allow packaging of large structures on small launch vehicles, and innovative materials and technologies to enable dynamically and thermally stable platforms. Specific topics of interest include:

- High strength-to-weight carbon nanotube-based composite materials for application to thrust structure, high-strength booms, thin shells, and membranes.
- Lightweight shielding, self-healing materials, and other countermeasures to protect spacecraft systems from harmful effects of space radiation, including materials development.
- Ultra-lightweight large structural concepts such as deployable and/or inflatable booms, membranes, and apertures for radiometer and synthetic aperture radar missions.
- Concepts, components, and materials to enable large, lightweight, diffraction limited optical systems including membrane optics.
- Dynamically stable structures utilizing integral vibration control and disturbance/payload isolation including spacecraft launch load isolation systems.
- Modular multifunctional structures with flexible imbedded electronics.
- Modular multifunctional structural material with imbedded fluids and control functions.
- Thermally stable materials and components and integrated thermal/structural concepts for high efficiency passive thermal management.
- Low cost, high power-to-weight efficiency deployable/inflatable solar arrays and structures.
- Technologies for mitigating the effects of meteoroids on critical platform components applicable to near-Earth missions.
- Methods for predicting and controlling contamination resulting from the deployment and outgassing of large platforms.
- Unpiloted Aerial Vehicles (UAVs) lightweight material and structure concepts.
- UAV material systems which enable multiple year mission operations.

E2.02 Guidance, Navigation and Control
Lead Center: GSFC
Participating Center(s): None

Future ES architectures will include collaborating assets used in performing coordinated scientific observations. These assets will include spacecraft, balloons, aircraft (both piloted and unpiloted), sounding rockets, and surface based systems. Advanced GN&C technology is required for each of these platforms that address low power, low mass, and low maintenance. A vigorous effort is needed to develop guidance, navigation and control methodologies, algorithms, sensors and actuator technologies to enable revolutionary Earth science missions. Exploiting new vantage points, developing new sensing strategies, and implementing system-wide techniques that promote agility, adaptability, evolvability, scalability, and affordability are characteristic of the technological challenges faced and are representative of the significant leap beyond the current state of the art required. Specific areas of research include:

Control Technologies

- Advanced sensors, actuators, and components with new or enhanced capabilities and performance, as well as reduced cost, mass, power, volume, and reduced complexity for all spacecraft GN&C system elements. Additional emphasis is placed on improved stability, accuracy, and lower noise.
- Low power, low mass, and low cost propulsive actuators and related subsystem components for generating attitude/orbit control torques/forces. Actuators to consume less than one watt of power at three volts, providing impulse bits on the order of one micro-N-sec for 3-axis control or 40 milli-N-sec for spin-stabilized control.
- Control theory, filtering techniques, processing advances, software architectures, and improved environmental models for attitude and trajectory determination and prediction. Filtering techniques and expert systems applications for near real-time trajectory determination and control. Methods for in-flight attitude sensor alignment and transfer function calibration.
- Autonomous execution of system functions including attitude and trajectory determination, monitoring of spacecraft functions and environmental conditions, assessing ground system and spacecraft health status, ground system fault detection, orbital event and attitude dependent prediction support utilizing advanced techniques such as fuzzy logic and neural networks.
- Techniques for autonomous in-flight fault detection/identification, fault correction and/or system reconfiguration.

Component and Design Technology

- Innovative testbed development capabilities and computer aided engineering, simulation and design tools with parallel algorithms for analysis and development of advanced GN&C systems. Open architecture object-oriented simulation tools and testbed systems for modeling and evaluting complex dynamic space systems.
- Vision-based GN&C system concepts, subsystems, hardware components and supporting algorithms/flight software. Innovative applications of high performance video image processing technology to provide alternative solutions to challenging GN&C problems such as spacecraft relative range/attitude determination while in close formation or during rendezvous/proximity operations.
- Rigid and flexible body control methods that are robust to parametric uncertainty and modeling error.
- Advanced GN&C solutions for balloon-borne stratospheric science payloads, including sub-arcsecond pointing control, sub-arcsecond attitude knowledge determination and trajectory guidance
- Concepts for autonomous guidance and control of spacecraft systems during atmospheric flight phases.

Spaceborne GPS Navigation/Attitude/Time System Technology

- Innovations in Global Positioning System (GPS) receiver hardware and algorithms that use GPS code and carrier signals to provide spacecraft navigation, attitude, and time:
  - Combined navigation/attitude space receivers, including advanced antenna designs/configurations
  - Navigation techniques that may employ Wide Area Augmentation System (WAAS) corrections
  - Navigation, attitude, and control for spacecraft proximity operations
  - Innovative uses of GPS which enable new Earth science measurements; for example, the use of differential GPS in repeating aircraft flight patterns and the use of ocean-reflected GPS signals

E2.03 Command and Data Handling
Lead Center: GSFC
Participating Center(s): None

Advancing science with reduced levels of mission funding, shorter mission development schedules and reduced availability of flight electronic components create new requirements for spacecraft Command and Data Handling (C&DH) systems. Specific technology areas for which proposals are being sought include:

Onboard Processing

- Volatile data storage - large capacity solid state storage media and data formatter are required to store instrument data until the next ground contact are currently weight and cost constrained. Development of components and packaging techniques that would allow greater density and lower cost components are necessary to support the higher science data rates, higher data volumes and smaller spacecraft of the future.
- General purpose data processing - higher levels of spacecraft autonomy require higher levels of general purpose CISC and RISC processing with fault tolerance and error correction (system and application). Development of

spacecraft computers that match or exceed the commercially available desktop computers is essential to meeting the "lights out" spacecraft control requirements.

- Special purpose data processing - higher levels of automated onboard science data processing such as histogramming, feature recognition and image registration are necessary to match the data gathering capabilities of future instruments with the limits of spacecraft to Earth communications. Development of technologies such as Digital Signal Processors (DSP) and of related hardware is necessary to address these future needs.
- Reconfigurable computing hardware - achieving pure hardware processing capabilities with the flexibility of reprogammability would allow different science objectives to be met with the same hardware platform. Development of technologies such as radiation hardened Field Programmable Gate Arrays (FPGAs) and of similar components for data communications and processing is necessary to achieve this goal.
- Low-power electronics - in order to provide higher capabilities on smaller less expensive spacecraft, lower power consumption components are essential to reducing solar array and battery sizes, affecting the overall spacecraft design. Development of low voltage, such as 3.3V or 2.5V or lower technologies, is essential to achieving the power constraints of smaller spacecraft.

Command and Data Transfer

- Subsystem data transfer - communications between various spacecraft subsystems become increasingly important in order to achieve higher autonomy. Development of technologies and architectures that increase the rate of data transfer above 20 Mbits/s are necessary to achieve the self-diagnosis, autonomous control, and science data transfer requirements.
- Intra-system data transfer - communications within the spacecraft subsystem (between cards within a box) are currently a limiting factor in achieving higher overall data throughputs. Development of technologies for communications within a box that would replace the conventional passive backplane is necessary to achieve higher science data throughput.

E2.04 Advanced Communication Technologies for Near-Earth Missions
Lead Center: GRC
Participating Center(s): None

To realize the ES Enterprise vision of Sensor-Web, a host of in-space and terrestrial communication link technologies are required. These technologies are likely to perform in an internet-based multi-point to multi-point communication architecture. Furthermore, in this architecture the spacecraft as well as the ground systems will be fully capable of interfacing to commercial communication networks to transport data directly to the users. Innovations are sought in space communications technologies for data delivery from NASA's future Earth Science enterprise near-Earth spacecraft, constellations and platforms directly to users. Advanced techniques and products are solicited that support communication among NASA spacecraft and commercial GEO networks for data delivery to users in a cost-effective manner. In addition, ever increasing demands are being placed on missions conserving bandwidth and power resources while driving up the demands for data transmission and access. Innovative communications technologies are sought at the device, subsystem and system levels in such areas as microwave, millimeter wave and optical communications; digital processing, modulation and coding; communications architectures and network technologies. Specifically, the required products are described below but are not limited to the following:

Data Communications Technology

- High rate data communication microwave or optical system technologies for supporting multi-Gigabit/sec data rates between and from spacecraft LEO, MEO or GEO orbits to ground networks. Communications include routing, encoding, encrypting of data to allow services on demand to address the need for autonomous spacecraft operations.
- Direct data distribution communication architectures (including multicasting) from LEO spacecraft directly to several users at various data rates and associated communication subsystems. Small, highly efficient, integrated communication receivers and transmitters for inter-spacecraft and constellation communications are needed.
- Communication link technologies to transfer data from an Earth observing balloon or airplane where the collection and transmission of data is by Internet protocols.

Component Technology

- Innovative approaches to enable higher frequency, miniature, power efficient Traveling Wave Tube Amplifiers (TWTAs) operating at millimeter wave frequencies. Of particular interest is the development of TWTA's that can operate at communication bit rates of 10 Gbps or higher.
- High, power wide, bandgap devices and amplifiers based on nitride semiconductors for efficient microwave power circuits.
- Low loss MEMS based RF switches are needed that would enable the development of reconfigurable antennas and filters for in flight control of the radiating frequency bandwidth and power.
- RF component and sub system technologies that enable integration for system on chip packaging type, such as mixed signal (analog/digital/optical) communication systems. Low cost, Ka band flat plate array antennas and low noise block down-converters are desired for small Earth terminals applications. Low cost, precision tracking Ka-band Earth terminals for high data rate (OC-3 to OC-12), direct-to-Earth downlinks from LEO/MEO spacecraft are also of interest. Wide scan angle (+/-60 degrees), low profile, transmit/receive Ka-band antennas; Ku-Ka band transcievers and closed loop acquisition/tracking algorithms for low-orbit space platforms and communication satellites are desired. Fractal-Element antennas are required for size reduction, broad or multi-bandedness, increased gain and beam agility.
- Digital components enabling space-based networking. Routers, switches, network interface cards, network processors, transceivers, etc. which can lead to integration and implementations in FPGA, ASIC, DSP chip solutions. Internet-based protocol modules and architectures that will provide seamless network continuity between terrestrial and aerospace-based platforms and environments.

E2.05 On-Board Propulsion
Lead Center: GRC
Participating Center(s): GSFC, JSC

This subtopic seeks propulsion technologies that will significantly increase capabilities and reduce costs for Earth science platforms. Propulsion functions include orbit insertion, orbit maintenance, precision positioning, in-space maneuvering, and de-orbit. Innovations in chemical and electric propulsion technology are sought for a range of spacecraft platform sizes to provide reduced mass, volume, and power while also providing increased flexibility in performing missions. Of particular interest are innovations in propulsion that lead to smaller-sized, integrated, autonomous spacecraft. The following specific areas are of interest:

Miniature/Precision Propulsion

- Propulsion technologies for nanospacecraft (< 20 kg) that emphasize system simplicity, low power requirements, and minimal mass. This includes concepts with fundamentally different approaches to propulsion than for macroscale spacecraft, leveraging micro-electromechanial system (MEMS) fabrication techniques. More robust substrate materials are also sought in addition to innovations in fabricating miniature propulsion systems.
- Propulsion technologies to provide high-precision (impulse bit < 100 milliNewton-second) stationkeeping and attitude control.
- Innovative, low-cost, reliable, self-contained propulsion systems for end of life de-orbit.

Thruster Technology

- High-performance, high-efficiency electric propulsion technologies, including thrusters and advanced power processing, for small, power-limited spacecraft.
- High-performance (specific impulse > 230 s), high-density monopropellant technologies, including propellant formulations, catalytic and noncatalytic decomposition methods, and chamber materials.
- High-performance (specific impulse > 325 s) bipropellant technologies for either non-toxic or hypergolic propellant systems.

Propulsion System Components

Propellant management components for electric and chemical propulsion systems that reduce total propulsion system mass and volume by a factor of two or better while improving reliability and life of existing components. Technology areas include:

- Materials compatible with high-temperature, oxidizing, and reactive environments
- Components for fluid isolation, pressure/mass flow regulation, relief quick disconnect, and flow control
- Techniques for metering, injection, and ignition of fluids in combustion devices
- Propellant (liquid and gaseous) storage and pressurization systems
- Components for xenon storage and flow control

E2.06 Distributed Spacecraft Systems
Lead Center: GSFC
Participating Center(s): JPL

Over the next 10 years, NASA will be launching ten distributed, spacecraft systems specifically for Earth science data collection. These distributed systems of orbiting components, which include spacecraft and support elements, such as mirrors and communication relays, will revolutionize approaches to conducting earth science. Distributed systems will operate under virtual infrastructures capable of responding to changing needs and conditions while evolving over time to introduce new capabilities. Distributed spacecraft systems also enable science investigations needed for the understanding of the total Earth system and the effects of natural and human-induced changes on the global environment. Representative mission scenarios include maintaining a specified satellite formation geometry at key points in the trajectory, maintaining the relative motion among co-orbiting spacecraft throughout the orbit, or maintaining relative positioning and attitude for targeting points on the Earth or capturing reflected angles off the Earth's surface or atmosphere. Distributed spacecraft concepts of collective pointing (pointing the formation at a particular target) or coordinated pointing (pointing the formation to collect related data from different selected angles) are critical to many of these mission scenarios. In addition to the dynamic behavior of each individual spacecraft, the collective behavior of all the spacecraft in the formation will determine the quality and the magnitude of the science return. Other formations such as large sparse antennas formed by a collection of miniature autonomous spacecraft containing the basic antenna elements arranged in an optimal geometric pattern represent an emerging novel approach to space-borne antenna design.

These distributed systems define a new paradigm in how we analyze, design, operate, and maintain space missions. In particular, in many cases, many of the spacecraft bus components, which were at one time virtually decoupled from the payload or science sensor, are now fully integrated and fully coupled together operationally. For example, there are a number of missions where the wavefront measured on an aperture distributed over multiple spacecraft would also be the primary information available for feedback as opposed to having independent navigation, ranging, or attitude determination sensors. Likewise, many of the elements of the bus which have generally been considered decoupled and virtually independent now are continuously, dynamically interacting, which significantly complicates the control. A primary example here is that the sensing and control of the attitude and orbit of the vehicle, for many formation flying missions, are interacting at rates from several times per orbit to several times per second. This drives the need for fully-autonomous, on-board, integrated control as opposed to traditional ground-based orbit corrections which happen very infrequently.

This subtopic calls for novel approaches to autonomous control of distributed spacecraft and the management of large fleets of heterogeneous and/or homogeneous assets. Submissions should focus on one or several of the following technologies and system-level concepts:

- Formation self-organization
- Reconfigurable control laws
- Robust and fault-tolerant control laws
- Algorithms for autonomous formation reconfiguration
- Nonlinear, robust estimation algorithms
- Integrated formation guidance and control
- On-board, closed-loop responsiveness to sensed events
- Low-cost approaches for formation navigation and control exploiting technologies such as GPS
- Optimal (e.g., minimum fuel, minimum time) approaches for formation maintenance and maneuvering
- Unique concepts for dealing with relevant perturbations and disturbances such as J2, solar radiation pressure, etc.
- New modeling techniques to support the technologies and concepts listed above

It is of significant interest to incorporate the use of expert systems, fuzzy logic, genetic algorithms, neural networks, discrete-event system methods, etc. as tools to support the proposed activities.

E2.07 Storage and Energy Conversion and Power Management and Distribution
Lead Center: GRC
Participating Center(s): JPL

Earth science observation missions will employ spacecraft, balloons, sounding rockets, surface assets, and piloted and robotic aircraft and marine craft. Advanced power technologies are required for each of these platforms that address issues of size, mass, capacity, reliability, and operational costs. A vigorous effort is needed to develop energy storage, power conversion, and power management and distribution technologies that will enable the revolutionary Earth science missions. Exploiting innovative technological opportunities, developing power systems for adverse environments, and implementing system-wide techniques which promote scalability, adaptability, flexibility, and affordability are characteristic of the technological challenges to be faced and are representative of the type of developments required beyond the current state of the art.

Storage and Energy Conversion Technologies
The energy storage and conversion technologies solicited include photovoltaics, batteries, regenerative fuel cells, alternative high-power-density storage technologies such as dual-use lightweight flywheels and ultra-capacitors. Specific areas of interest are:

- Battery technologies are needed for spacecraft requiring greater than a 100 watt-hour per kilogram specific energy density and a10-year lifetime in LEO and GEO. Rechargeable lithium ion batteries with advanced anode and cathode materials and liquid/polymer electrolytes and other advanced battery systems capable of meeting the above performance criteria are of interest. For some terrestrial missions, batteries are needed which are capable of delivering 30-50 percent of their ambient specific energy at temperatures as low as -100 C.
- Regenerative fuel cell technology is of interest to NASA because it is an enabling technology for some robotic terrestrial Earth observation missions. Improvements in specific energy cycle life, cost, and operational overhead are needed for small regenerative fuel cells utilized in balloon and other terrestrial observation missions.
- Future micro-spacecraft require distributed power sources that are integrated with microelectronics devices/instruments. These microelectronic devices/instruments require rechargeable batteries/fuel cells that can provide power in the micro to milliwatt range. Due to the low thermal mass of the micro-spacecraft in LEO, these spacecraft must operate over a wide temperature range (-100 to 100 C). Long cycle life performance capability is also needed for micro-rechargeable batteries.
- Power systems based on micromachining fabrication techniques and in energy storage components based upon carbon nano-tube technology and ultracapacitors.
- Photovoltaic technology with significant improvement(s) in: efficiencies, cost, radiation resistance, and wide/low temperature operation are solicited. Potential concepts include rigid arrays, thin film arrays, and various concentrator configurations.
- Advanced solar thermal power conversion technologies for Earth orbiting spacecraft and/or orbit transfer vehicles are of interest. Concentrators may be rigid or inflatable, primary or secondary and address issues such as manufacturing, coatings, efficiency, packaging/deployment, and pointing/tracking. Receivers may utilize heat pipe or direct absorption technologies intended to minimize mass and volume. Topics of interest in power conversion include the investigation of compact heat exchangers, advanced materials, and control methods as they relate to life, reliability and manufacturability. Heat rejection areas of interest include composite materials, heat pipes, pumped loop systems, and packaging and deployment. Also of interest are highly integrated systems that combine elements of the above subsystems and show system level benefits.

Power Management and Distribution Technologies
Innovative concepts utilizing advanced technologies are needed to manage and distribute power in lighter, smaller, cheaper, more durable, and higher performance are required for terrestrial and space Earth observation missions. Advances for power management and distribution (PMAD) systems are sought in the following areas:

- Technologies which enable materials, surfaces, and components to be durable in atomic oxygen, soft x-ray, electron, proton, and ultraviolet radiation and thermal cycling environments, lightweight electromagnetic interference shielding, and high-performance, environmentally durable radiators are of interest to NASA.
- Advanced electronic materials, devices and circuits are of interest. Capabilities include but are not limited to transformers, transistors, integrated circuits, capacitors, ultra-capacitors, electro-optical devices, micro-electro-mechanical systems (MEMS), sensors, low loss magnetic cores. The area of packaging with improved characteristics capable of wide-temperature operation and/or radiation resistance for use in PMAD systems, motor drives, electrical actuation, or electro-mechanical systems are also of interest.
- Thermal control technologies that are integral to electrical devices with high heat flux capability and advanced electronic packaging technologies that reduce volume and mass or combine electromagnetic shielding with thermal control are sought.
- Management, control, and monitoring of power systems for autonomous operation in space are of interest to NASA. Capabilities include: fault detection, isolation, and system reconfiguration with including "smart components", built-in test, vehicle health management concepts, improved wiring system designs, and advanced circuit protection to improve safety, reliability, and performance of terrestrial and space craft.
- Advanced PMAD electronics for small, low cost spacecraft are sought to simplify interfaces, streamline integration and testing, and reduce size and mass.
- Innovative technologies are sought for advanced power-conditioning devices used for housekeeping and control of a wide range of regulated voltages on Earth Science payloads to reduce size and mass utilizing hybrid, multi-chip, and other techniques.
- Modular, integrated spacecraft PMAD building blocks are sought to drastically reduce the system size, mass, and recurring cost through the use of the highest levels of integration based on monolithic, application-specific integrated circuits, mixed mode application-specific integrated circuits, field programmable gate arrays, advanced power packaging techniques, and flexible reusable architectures.

E2.08 Life-Cycle Integration, Validation, and Distributed Collaboration Technologies
Lead Center: LaRC
Participating Center(s): JPL, LaRC

The NASA Earth Science Missions seeks to address all aspects of design development and life-cycle management, including the ability to determine complete life-cycle requirements and costs early in the design cycle. There is a critical need for modeling, simulation, and asynchronous technologies that support integration throughout the entire life-cycle of a mission, project, or vehicle (a typical NASA life-cycle is on the order of 30 years). This integrated capability must be supported across diverse geographic, cultural, and computational environments and be used in and across Earth Science organizations. This subtopic is focused on component design and commercial advanced technologies that support the advancement of engineering tools, and engineering methodologies in Earth Science integrated program and project laboratories.

There are many emerging technological concepts that show promise as potential integrated technologies. Examples of some existing concepts which HAVE NOT been incorporated into integrated data life-cycle management are: (1) Intelligent Agents (push/portals/information dissemination, (2) Collaborative Analysis and Design, (3) Data Mining, (4) Project Management Integration, (5) Document Collaboration, (6) Library, (7) Workflow/Status Checking, and (8) Infor- mation Compartmentalization to reduce information overload. Areas of interest include:

- Software system architectures that enable life-cycle simulation systems to be assembled quickly and tailored for specific vehicles or missions. Such systems must be compatible with legacy software codes and must permit the insertion of research technology by users.
- Rapid model assemblers technology that enables components and a knowledge base to assist the modeler in providing validated model data suitable for the simulation and analysis of the entire life-cycle of a product.
- Advanced rapid life cycle simulation tools.
- Advanced intelligent systems for knowledge capture of design and the design process and engineering process assessment methodologies.
- Software systems and products that reduce the effort required for creating immersive visualization displays of intermediate simulations are necessary to validate real time modeling results. Such systems must be general enough to support the entire life-cycle of NASA's diverse missions and vehicles.

- Distributed collaboration tools that support the integration of life-cycle analysis in both modeling and simulation.
- New technologies that allow collection, storage, and retrieval of various forms of integrated data (graphical, text, photo, email, sound, etc.) associated with a process life-cycle (full life-cycle greater than 30 years).

E3 Advanced Information Systems Technology

The Earth Science Enterprise (ESE) acquires, processes and delivers very large (gigabyte to terabyte) volumes of remote sensing and related data to public and government entities that apply this information to understand and solve problems in Earth science. Information technology is currently employed throughout ESE's space and ground systems, and the Advanced Information System Technology theme is soliciting technologies that apply to the end-to-end system functions. The information system functions found in ESE include but are not limited to data acquisition, data transmission, data processing, data management and storage, data distribution, data/metadata/document search, browse and assess, data subsetting, knowledge discovery, spatial-temporal analysis, and visualization. The ESE is interested in advanced information technology that can improve any of these functions in isolation or in combination or is able to support alternative architectures that better address the scientific requirements.

E3.01 Knowledge Discovery and Data Fusion
Lead Center: JPL
Participating Center(s): None

NASA's Earth Science Enterprise collects terabyte-scale datasets routinely during its missions and charges the scientific community with extracting usable and scientifically relevant information from them. These data sets may be images, multispectral images, time series, or field and particle event lists. They may also be engineering time series about spacecraft health collected from on-board sensors. Emphasis has recently been placed on handling and analyzing in situ data from networks or sensorwebs. In addition to the ongoing challenges entailed by handling, analyzing and mining very large data sets, NASA now needs a new framework for performing science data evaluation onboard spacecraft and from in situ sensor networks. New onboard or in situ science capabilities will enable mission activities to be directed by scientists without the assistance of a ground sequencing team and the constraints of communications links. The science capabilities will be adaptive in nature and must be efficient in transmission of the usable key data.

This subtopic enlists help in developing a new generation of tools and algorithms for effective acquisition and analysis of data and image sets appropriate for ground or onboard/in situ use. Of special interest are: (1) the ability to deal quantitatively with uncertainty present in data, perhaps in a statistical framework; (2) development of flexible models through which observables are linked to quantities of scientific or engineering interest; (3) harnessing database technology for organizing the observed data, models, and inferred knowledge, perhaps in onboard or in situ archives; (4) fusion of multiple datasets for enhanced scientific return; and (5) system concepts for handling interactions between onboard science analysis and event detection capabilities and other functions of an autonomous spacecraft or sensor web. One or more of these areas should be addressed by every proposal. Specific technologies of interest would address:

- Automated classification of data
- Supervised and unsupervised learning methods
- Knowledge discovery techniques
- Image analysis and segmentation
- Statistical pattern recognition
- Time series feature extraction and analysis
- Trainable object recognition
- Automatic image registration and change detection
- Visualization and rendering techniques
- Spatial-temporal data mining
- Intelligent, goal-directed data acquisition and/or compression
- Science data analysis algorithms designed for scalable computing

- System concepts for onboard science
- Adaptive data acquisition techniques

E3.02 Automation and Planning
Lead Center: ARC
Participating Center(s): None

Focus is on technologies that make a spacecraft or system react to uncertainties in a robust fashion while achieving a set of high-level goals or tasks. Technology innovations in automation and autonomous systems are required to support the high level command collection and effective techniques for processing large volumes of data into useful information. Intelligent data discovery and searching over heterogeneous data in distributed data stores. Collaboration between Earth scientists and computer scientists is encouraged for these proposals to demonstrate useful results. Areas of interest in technological innovation include:

- Autonomous agents: Intelligent autonomous mobile search agents to support science applications involving data available on the Internet
- Autonomous data collection: Automatic dynamic reconfiguration of UAV or space on-board data gathering instruments to make effective use of observing conditions, baseline image data priority scheme, history of observations and limited on-board resources
- Planning and scheduling
- System health and maintenance (space and ground based)
- Distributed decision making (multiple agents, autonomous systems)
- Automated software testing
- Legacy code maintenance and conversion
- Automatic software generation (i.e., processing algorithms)
- Software tools for parallelization; tools for production planning
- Control of FPGA to provide real-time products using hyper-spectral instrument data from airborne platforms
- Verification and validation of automated systems

E3.03 High Performance Computing and Networking
Lead Center: ARC
Participating Center(s): GSFC

This subtopic focuses on innovations in efficient and effective techniques and technologies for processing large volumes of data into useful information. Areas of interest include:

- High performance processing
- Computing: Distributed computing, Reconfigurable computing, Parallel/cluster computing, Embedded computing, Optical computing
- Future computing and storage device technologies: quantum computing, atomic chain electronics, molecular computing, nano and quantum device technologies, and carbon nanotube based electronic devices and proposed architectures
- Innovative node connection networks
- High performance/pervasive networks
- Techniques to enhance performance of wide-area networks supporting highly distributed data production, archive, and access functions
- High-speed processing architectures/systems; applications of distributed computing environments, especially "pervasive computing"
- Efficient methods/algorithms/systems for warehousing scientific multispectral and hyperspectral data and/or instrument data for automatic and user-directed mining/monitoring of meaningful trends, parameters, fluctuations, etc. to maximize scientific value of TB-sized data sets
- Facilitating portability across architectures
- Advanced Storage and archival techniques (e.g., 3D holographic memory, holographic storage)
- Load balancing techniques

- Standards to simplify data providers' activities while facilitating data usage by a large user community
- Server side technologies supporting highly responsive user-centric access (e.g., handheld PDAs to large date centers)
- Software development environments and methodologies
- Work scheduling as applied to distributed computer systems

E3.04 Geospatial Data Analysis Processing and Visualization Technologies
Lead Center: SSC
Participating Center(s): None

Proposals are sought for the development of advanced technologies to enhance human and machine interaction in support of scientific, commercial and educational application of remote sensing data. An emphasis is on distributed and/or mobile teams in validation and verification exercises and for the commercialization of remote sensing data. Focus areas are to provide tools for interpretation, visualization or analysis of remotely sensed data and to provide qualitative and quantitative analysis tools and techniques for performance analysis of remotely sensed data. Applications can support the commercial remote sensing industry and enhance the commercial or educational application of Earth science data. Areas of specific interest include:

- Unique, innovative data reduction and rapid analysis methodologies and algorithms, particularly for hyperspectral data sets
- Innovative techniques for validation of imaging systems (i.e. thermal and LIDAR imaging systems)
- Software tools for mobile computing and efficient data collection and/or presentation
- Innovative approaches for incorporation of GPS data into in situ data collection operations with dynamic links to spatial databases including environmental models
- Innovative techniques to automate quality assurance processes for science data products
- Distribution and sharing of fused science data sets to correlate similar data sets from diverse spacecraft and aerial vehicles and provide unique, commercially useful information products
- Data merge and fusion software for efficient production and real-time delivery of commercial digital products to teams and remote users
- Tools for enabling distributed scientific collaboration
- Software to automate the rapid processing and distribution of sub-setting and presenting RS data over a network
- Software to develop commercial products from digital topography and vegetation canopy data obtained from airborne and space-based active optical sensors
- Innovative approaches that contribute to the understanding of data through the display and visualization of some or all of the above data types including providing the linkages and user interface between the cartographic model and attribute databases
- Visualization of multi-variate geospatial data including remotely sensed data from the following:
  - airborne and satellite platforms, vector data from public and private archives;
  - cartographic databases from public and private sources;
  - continuous surface data held as a raster data model; and
  - 3-D data held in a true 3-D raster model.

E3.05 Data Management and Visualization
Lead Center: GSFC
Participating Center(s): None

This subtopic focuses on innovative approaches to locating, summarizing and presenting large collections of Earth science data in a highly distributed and networked environment. Collaboration between Earth scientists and computer scientists is encouraged for the proposals to demonstrate useful results. Specific examples of topics of interest are:

- Design and implementation of a virtual reality CAVE for scientific data visualization Ideas can include: 3-D virtual reality environments that will let users 'fly' through the data space; precomputed data fly-throughs that let users search within the fly-through space (i.e. fast forward, reverse, slow motion) to locate specific areas of interest; incorporation of commodity data compression techniques (such as HDTV/MPEG) for reduced storage and transmission requirements; progressive compression and caching techniques that optimize resolution and performance when zooming in for additional detail; techniques for georectification, data overlays, data reduction, and data encoding that work across a distributed environment of widely differing data types and formats; development of integrated object oriented storage and compression techniques that are integrated into search algorithms; novel 3-D presentation techniques that minimize or eliminate the need for special user devices such as goggles or helmets; techniques for high bandwidth collaboration with other users in a distributed environment; development of techniques that invoke integrated visual and auditory presentation cues; data viewing and real-time data browse, including fast, general purpose rendering tools for scientific applications; viewing of multi-variate geospatial data including remotely sensed data.

- Support a collaborative environment with tools that facilitate outreach and problem solving. This environment stimulates government & business partnerships with emphases on detailed data analysis conversion capabilities to translate science & technology data into information used by specialty communities for making decisions.
- Tools for enabling distributed scientific collaboration.
- Technologies supporting management, storage, search and retrieval of very large, distributed, geo-spatial earth science data volumes: Tools to facilitate automatic data product legacy, quality assurance and metadata updates. Object relational technologies specific for Earth sciences. Meta-data discovery to facilities the automated use of data from different sources. Automatic metric collection and analysis for data use and data ordering. Smart Objects Dumb Archives (SODA) and storage, archival and retrieval standards applicable to ESE mission requirements.

E4 Applying Earth Science Measurements

The Earth Science Enterprise (ESE) continues to search for solutions on how the global environment is changing and the effect these changes have on the human societal and economic environment. The planet's continual environmental change, the increasing human ability to influence the environment and accelerate the uses of science in practical uses is of strong interest to the Enterprise. Innovative tools and techniques that are easy to access and use are needed to produce information from Earth science measurements. This information will help guide systemic organizational change in the uses of the planet's resources that can result in a balance of sustainable global economic development with the preservation of the Earth systems’ ability to renew itself. The goal of this topic is the routine use of Earth science results by a broad user community that works daily with land/biota, air, water, educational, and emergency issues.

E4.01 Special Event Imaging and Other Earth Observing Instruments
Lead Center: MSFC
Participating Center(s): None

Proposals are sought for the development of innovative technology for the observation of short-lived phenomena in the Earth's atmosphere, oceans, and land. These innovations will make important contributions to the ESE’s science and application themes. Areas of interest include but are not limited to phenomena such as severe weather, thunderstorms, lightning, volcanoes, wildfires, flash floods, and ocean blooms. These innovations are intended to increase our understanding of the effects of short term forcing on the interacting physical, chemical and biological processes that affect the environment in which we live. In addition, it is anticipated that proposed innovations should directly contribute to the ESE goal of predicting and mitigating natural hazards. Atmospheric measurements of interest include meteorological parameters that play important roles in short lived phenomena including clouds, precipitation, lightning, cloud ice, water vapor, aerosols, winds, temperature and chemical constituents and effluents. Surface measurements include temperatures of ocean and land, ocean productivity and color, terrain mapping and changes, vegetation index and biological productivity. Sought after technological advances include techniques that lead to improved temporal, spatial and spectral response to the above-described geophysical phenomena. These advances may be at the component, subsystem, and complete system level and should address reduced size, weight or power, improved reliability and lower cost in addition to the requirements for improved performance. These innovations should expand the capabilities of airborne systems (manned and unmanned) and the next generation spaceborne systems. Innovative sensor approaches are an important element of competitive proposals under this solicitation:

- Storm/cloud sensing technology used to obtain a proxy to the instantaneous internal convective strength of storms and its relationship to latent heat release and transport.
- Lightning sensing technology to measure total flash distribution, frequency and intensity, and provide flash type discrimination (e.g., intracloud versus cloud-to-ground lightning).
- Technology to aid in the mitigation of wildfires, either by early detection or through the measurement of phenomena that contribute to or initiate fires.
- Agile optical sensors with high temporal, spectral, and spatial resolution.

E4.02 Advanced Instrument Technology for Transitional Boundaries of Land and Water
Lead Center: SSC
Participating Center(s): None

The coastal zone represents a dynamic environment subject to both natural and anthropogenic influences. Innovative technologies are sought for the measurement of biological, chemical, and geological processes characteristic of this environment. Potential new measurement instrumentation include the following:

- Surface and subsurface water variables (e.g., chemical composition, nutrient content, biological/organic content, optical properties, temperature, salinity, suspended materials) and their changes with depth;
- Changes in vegetation occurring on small spatial scales or for which the spectral response is influenced by changing water levels;
- Natural hazards (e.g., hurricanes and sea level rise) and man-induced pressures on land use/land cover in near shore areas (e.g., particulate loading, nutrient loading);
- Physicochemical properties associated with subsurface soil and sediment and their changes with depth in environments covered by water or vegetation, and
- Atmospheric variables necessary for the correction of remotely sensed data (e.g., aerosol absorption, ozone absorption, oxygen and water vapor absorption, atmospheric path length, Rayleigh scattering, aerosol size distribution, and Mie scattering).

Efforts should emphasize the development or improvement of technology applications in areas such as instrumentation and tools for data analysis to support these areas of study. Applications technologies should support both scientific research and sustainable economic development of the coastal zone.

- Airborne and ground based multispectral and hyperspectral-imaging systems providing improved spectral resolution (e.g., less than 10 nm bandwidths, and less than 1nm resolution). Spatial resolution (e.g., less than 30 cm ground sampling distance) with higher sensitivities (e.g., .05 NedL) and signal to noise ratios (e.g., greater than 1000:1) necessary for water observations but with the dynamic range (e.g., albedo of .01 to .5) to include terrestrial observations as well.
- Ancillary data collection for imaging systems which, including the integration of the Global Positioning System, coordinates system, platform attitude, altitude, radiometric and atmospheric data characteristics.
- Improved data processing and analysis systems for image data mosaics, geometric correction, atmospheric correction, radiometric correction, and formatting for ease of analysis.
- Instruments for measuring apparent and inherent optical properties of rivers, lakes and oceans.
- Improved instruments for enhancing the collection of water samples and in situ measurements with equipment deployed from small and large research vessels (e.g., profiling instruments).
- Instruments for measuring bio-optical fluorescence of particles in water.
- Data acquisition systems that integrate multiple sensors integrated data analysis software, networking of multi-sensor arrays, autonomous acquisition and transmission.
- Improvements in ground penetrating radar to improve portability expand frequency ranges, receiver sensitivities, software analysis tools, and integration of ground penetrating radar data with other sensor systems.
- Instruments and tools for in situ and in vivo analysis of terrestrial and aquatic plant bioactivity (e.g., evapotranspiration, optical properties, fluorescence, chlorophyll content, and nutrient uptake).
- Instruments for collecting and analyzing bottom sediments in water for particle size distribution, nutrients, metals and radionuclides.

E4.03 Innovative Tools and Techniques Supporting Earth Science Measurements
Lead Center: SSC
Participating Center(s): GSFC

Proposals are sought for the development of new technologies and technical methods that make Earth science measurements easy to use by practitioners in the areas of community growth, disaster management, environmental quality and resource management. This subtopic seeks proposals with team members supporting the development of end-to-end systems that ingest data to produce information for an end-user community. Proposals should address the full range of technologies; aeronautical, space, in situ instrumentation, computational methods, distribution and capabilities required for the proposed development. Developments should take into consideration operational requirements across different operating systems, computing platforms, wired and wireless communications capability and the technical sophistication of the end user.

Community Growth
Innovative technologies are sought in the diverse area of community growth which includes urban planning, real estate, utilities, transportation and engineering/construction/development.

- Urban planning applications include the monitoring of urban growth including the evolution of the correlative transportation infrastructure, cadastral mapping, and the production of maps and other analyses within a GIS utilizing satellite images as input.
- Utilities applications involve gas, electric, water, and telecommunications infrastructure and include monitoring and site planning and development.
- Transportation applications cross land, sea, and air and include everything from mapping of the evolving road, highway and rail network, pipeline routing and monitoring, cost-surface analysis of new transportation routes, traffic monitoring, monitoring barge traffic, international shipping, and sea ice. An additional transportation application involves the monitoring of volcanic eruptive plumes to reroute air traffic.
- Engineering/Construction/Development applications include site and infrastructure mapping, soils, runoff, and drainage mapping, and boundary mapping.

Disaster Management
Proposals are sought to develop new instrumentation to perform hazard assessment/risk exposure, disaster monitoring, and damage impact assessment related to either natural or manmade disasters. Applications include the requirements of public and private first responders and early warning systems. Major natural hazards categories include earthquakes, volcanic eruptions, tsunamis, landslides, wildfires, flooding, and severe storms. Major man-made disasters include oil and other chemical spills, catastrophic release of airborne pollutants, catastrophic release of radioactive materials, and ruptures of reservoirs and pipelines.

The disaster management sector is involved with the operational logistics and mitigation of natural disasters as well as post-disaster damage impact assessment. The disaster management theme also includes all insurance applications. The insurance and disaster management industries are related, in that they both deal with the risk of natural disasters and managing activity before, during, and after disasters. Typical requirements include land cover characterization and DEM analysis to assess flood hazards, coastal mapping to assess hurricane and storm risk, and mapping of fuel loading to understand brush fire hazard.

Environmental Quality
Proposals are to perform a diverse array of activities that generally relate to air and water quality and include instrumentation for monitoring, management, and mitigation/remediation of groundwater and soil pollution, acid mine drainage and other effects of surface mining and solid waste. Other activities relate to ozone and acid rain, wetlands, analysis of environmental impact of development, non-point source pollution and analysis of urban heat islands. The disruption of the environment by nitrogen fertilizers, phosphorus, and runoff of animal waste from animal farms is also included.

Resource Management
New technologies are sought for balancing the resource demands and growth of populations with natural resource availability and sustainability. The natural resources applications include several broad types of activity: agriculture,

forestry, range-land management, nonrenewable and renewable energy, extraction (mining), conservation, fisheries and analysis of the regional impacts of climate change.

- The agricultural sector includes private farmers, agribusiness, government agencies and commodities forecasting, analysis, and speculation.
- The forestry sector includes global timber and paper businesses, government agencies and forests around the world.
- Range-land management includes land use assessments, planning and monitoring the health of large ranches, and Federal lands.
- Nonrenewable energy applications include the exploration and development of oil, coal, and uranium. Renewable resource applications include analysis of solar and wind energy potential.
- Extraction includes the mining of minerals on all scales.
- Fisheries include industrial, commercial, and sport fishing, as well as fisheries management and conservation. Fish are defined broadly to include all living animals harvested from the ocean or inland water bodies.

E4.04 Advanced Educational Processes and Tools
Lead Center: GSFC
Participating Center(s): ARC, JPL, LaRC, MSFC, SSC

This subtopic focuses on innovation in effective applications related to classroom or museum ready software tools for display and/or analysis of Earth science information for learners in both formal and informal settings, and tools for organization and dissemination of NASA's Earth Science educational materials to a wide array of educational audiences. The Earth Science educational program covers a wide range of audiences from students to adults in both classroom settings such as public schools or continuing education venues to all matter of informal learning settings such as radio, television, museums, parks, scouts, and the internet. In these venues the learning focuses on the scientific discoveries by the Earth Science enterprise, the technology innovations and the applied use of these discoveries and technologies for improved decision making by all.

The areas of interest (described below) cross-cut the 3 programmatic areas within the Earth Science Education program (formal, informal and professional development) and hence are anticipated to have utility in at least 2 of these areas and most likely in all three areas.

The first area of interest focuses on innovation in the application of digital library technologies to educational materials and audiences. The successful proposal must be able to interface with or be integrated into existing educational digital library efforts within NASA's Earth Science Education program. These proposals will advance the use and usability of globally distributed, networked information resources, and encourage existing and new communities to focus on innovative applications areas. Collaboration between Earth scientists, formal or informal education community professionals, and computer scientists is required for these proposals to demonstrate useful results. Areas of interest include:

- Extend the current Joined Digital Library (JOIN) effort by developing additional Jini applications. JOIN is a collection of tools based on Sun's Jini technology used to implement efficient, decentralized, and distributed computing systems and follows "the network is the computer" philosophy.
- Development of formal and informal education audience-specific interfaces (for example but not limited to: specific interfaces for students, Park interpreters, TV producers, curriculum developers, etc.).
- Development of interfaces to promote diversity within educational audiences (such as but not limited to age, ethnicity, cultural, urban/rural, etc.).
- Development of accessibility tools for disabled users to interact and search digital libraries.
- Development and access to educational materials including new resources for science, mathematics and engineering education at all levels.
- Development of interoperability tools to integrate dissimilar library archives.
- Develop applications that enhance the general functionality of existing digital libraries by providing new general purpose tools for archive management, metadata ingestion, intelligent search and retrieval.
- Tools to support online community interaction, which could include new means for gathering, interacting, and communicating with other library users.

The second area of interest focuses on innovation in effective software and related development techniques, and in highly practical methods for maintaining and disseminating software for use by educational audiences engaged in teaching or learning about Earth science. The specific areas of greatest interest are highly-portable, classroom-ready software for analysis, visualization and processing of Earth science satellite data, and methods to provide long-term support and viability for educational software. Collaboration between Earth scientists, educators, computer scientists and "business" model experts is required for these proposals to demonstrate useful results. Areas of interest include:

- Extend the current Image2000 effort by developing additional plug-in applications and modifying core software if necessary. Image2000 is a Java/JAI-based image processing package being developed at GSFC.
- User-friendly, extensible, Earth science satellite image processing software for multiple operating systems, for educational use in K - 12, undergraduate and continuing education venues.
- Techniques and software for integrating vector and raster data for the visualization and analysis of geo-spatial Earth science data.
- Tutorials geared toward the use of image processing software for visualization and analysis of Earth science related satellite imagery.

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8.1.4 HUMAN EXPLORATION AND DEVELOPMENT OF SPACE

The mission of the Human Exploration and Development of Space (HEDS) Enterprise is to open the space frontier by exploring, using and enabling the development of space and to expand the human experience into the far reaches of space. In exploring space, HEDS brings people and machines together to overcome the challenges of distance, time and environment. Robotic science missions survey and characterize other bodies as precursors to eventual human missions. In using space, HEDS emphasizes learning how to live and work there and utilize the resources and unique environment. In enabling the development of space, HEDS serves as a catalyst for commercial space development. Throughout, this Enterprise will employ breakthrough technologies and ingenious designs to revolutionize human space flight.

http://www.hq.nasa.gov/osf/heds/

H1 Systems Integration, Analysis and Modeling

The goals of this topic are to enable the optimization of investments made in technology for human/robotic exploration and development of space. This includes identification and refinement of advanced system and architecture concepts that may dramatically increase the safety and reliability -- and reduce the cost -- of ambitious future human exploration missions and campaigns beyond Earth orbit. This topic also encompasses establishing a foundation of relationships with the science community and potential commercial or international partners for future exploration activities. Specific objectives of this topic involve the development and validation of innovative new analysis/modeling tools and techniques for (1) conducting advanced concepts studies to create/identify innovative new approaches to human exploration and the development of space, (2) conducting detailed, end-to-end architecture studies incorporating the most promising new systems and infrastructure concepts (3) defining and refining strategic research and technology road maps to provide ongoing guidance to technology development efforts.

H1.01 Process/Industrial Engineering Technologies
Lead Center: KSC
Participating Center(s): ARC

Spacecraft launch and payload processing systems have many unique aspects which require development of innovative process or industrial engineering (IE) technologies in order to obtain the substantial benefits derived from applying IE principles in other industries. Process/Industrial Engineering is a technical discipline emphasizing the interfaces between people, processes, and hardware/software systems in a specific work environment. Process/industrial engineering is devoted to the science of process improvement and optimization of operational phases of complex systems. The Space Shuttle is NASA's first major program with a long-term operational phase. All major current and potential future human space flight programs (the International Space Station, X-vehicles, and extended human exploration) are also projected to have lengthy operational phases. Payload processing activities emphasize repeatable processes and improved customer satisfaction. Therefore, the strategic importance of IE technologies to NASA is rapidly increasing. Advanced spaceport technologies for designing, improving, and managing processes are needed to support spacecraft ground processing at KSC. Process/industrial engineering technologies should support NASA's goal of achieving safe, reliable, and low cost space access. Proposals should also identify potential applications for enhancing the operational phases of new NASA programs and aviation depot maintenance processes. Proposals may address the development of new concepts, methodologies, processes, and/or software support systems which advance the state-of-the-art in one or any combination of the following general areas of interest: operations research; process simulation modeling; statistical process control; planning and scheduling systems; project management risk analysis; decision analysis; cost-benefit analysis; task/work methods analysis; work measurement; human factors engineering; ergonomics; performance metrics; and management information systems. Specific interests for the 2001 solicitation include, but are not limited to, those listed below:

- Simulation tools that assist engineers in process or product design and development while reducing human error risk factors.
- Development of project management tools that identify project or system risk factors while assessing cost and schedule impacts.
- Toolkits for advanced task/methods analysis and procedure design technologies (including process failure modes and effects analyses) for complex, long-duration, and infrequent spacecraft test and checkout activities.
- Development of computer-based training for writing human-centered procedures. Development of evaluation methods and metrics for procedure re-design.
- Advanced technologies for generating and delivering effective test and checkout procedures. Knowledge-based tools and methods for providing highly effective just-in-time task level training in the operational environment.
- Knowledge-based systems engineering tools for predicting operational technician traps and recommending effective design alternatives.
- Tools to measure and improve human-computer interaction with computer consoles and portable data collection devices.
- Advanced operations research and human factors engineering tools for optimizing utilization of scarce resources and minimizing the potential for human error during depot-level maintenance of reusable launch vehicles and aircraft, expendable launch vehicle test and checkout activities, and payload processing activities.

- Advanced statistical quality control techniques for ensuring high quality, affordable manufacturing and maintenance of unique spacecraft hardware. Automated statistical quality control algorithms that can be applied to data streams generated by space vehicle and ground hardware/software health monitoring systems.
- Advanced operations process modeling, simulation, verification and validation technologies for cost-effective evaluation of the impacts of proposed changes to operational processes and procedures. Proposed changes include hardware/software upgrades, process enhancements, and technology infusions.
- Operations research technologies enabling seamless integration of airports and spaceports of the future.

H1.02 Systems Architecture and Infrastructure Modeling
Lead Center: MSFC
Participating Center(s): None

This subtopic focuses on the development of innovative computer based tools that can effectively evaluate and analyze competing technologies for future HEDS requirements from a systems point-of-view. These tools should include state-of-the-art breakthroughs and beyond. The tools should be adaptable to various NASA missions as well as to the non-space community. This subtopic should act as a building block to ultimately achieving an end-to-end evaluation tool that identifies the technology development that is required. This will reduce program cost and schedule while increasing the safety and reliability of future missions. The tools developed and matured under this subtopic should embrace the direction that advanced programming has been heading such as virtual reality, neural networks and fuzzy logic. Specific areas of interest include:

- A general purpose concept analysis and design optimization tool that provides the capability to evaluate or optimize a hierarchical system design based on user defined goals, parameters and criteria.
- Graphical user interfaces (GUI) for depicting the hierarchical structure, relationships between systems and friendly user interfaces.
- Automate the input of data or the transfer of output data to other software tools.
- Optimization requirements including user defined goals and interactive changes to design parameters.
- Biologically inspired design optimization algorithms such as automated reasoning, genetic algorithms and neural networks.
- Modeling structure that can accommodate systems and subsystems with their technology options. The model structure should be mission generic yet capable of capturing HEDS systems elements for assessing specific mission concepts. For example, the model should be capable of assessing the impact of specifying that a particular technology option be used for all elements in mission architecture, including vehicle, surface and orbital infrastructure subsystems.
- Interfaces for interchange of data or sharing of capabilities between models or concurrent execution. This includes the development of standards for subsystem models and modification or design of hooks within existing models for input/output transfer and use of a common technology database.
- Common databases with technology performance and cost data. The tools should have the capability to ensure that common data is being used appropriately in all models.
- The tools should link the models and databases into a system to allow for trade studies, sensitivity analysis and identify the required technologies that need to be developed.
- Tools with the capability to perform system and technology sensitivities in order to identify mission architecture impacts.
- Tools that model technology performance, analyze competing technologies and then identify promising exploration concepts, architectures, and metrics to focus on technology development.

This subtopic focuses on developing innovative computer based tools that can evaluate and analyze competing technologies from a systems point-of-view will allow the proposers to have a product suitable for marketing by the end of phase III. The tools should be applicable to a number of different industries.

H2 Space Resources Development

The goals of this topic are to drive down the cost of human/robotic exploration missions and campaigns. This includes supporting improved health and safety for human explorers beyond Earth orbit. It also includes working with the space science community to test concepts and technologies. The objectives of this topic include: (1) Developing and validating the technology to utilize local resources, such as Regolith/Minerals, Ices and Atmosphere -- in order to (2) Produce, process and deliver consumables, including propellants (storable and cryogenic), life support and other gases and water. (3) Fabricate key physical structural systems and their elements from local materials. This includes radiation shielding, structural elements (e.g., trusses, panels, etc.), and mechanical spares for mission system elements. (4) Enable local fabrication of selected "finished products" and/or "end-items" including photo-voltaic cells and solar arrays, wires, tubes, connectors, etc., and pressurized volumes. (5) Testing key technologies and demonstrating innovative new systems concepts in space. (6) Establishing a foundation for profitable commercial development of the resulting technologies in the mid- to far-term.

H2.01 In Situ Resources Utilization of Planetary Materials for Human Space Missions
Lead Center: JSC
Participating Center(s): ARC, KSC

Significant benefits for future human missions to the Moon, Mars, and other planetary bodies may be attained by making maximum use of local, indigenous materials as a source for products such as propellants, life support consumables, radiation protection, and construction materials. By pursuing the philosophy of "make what you need at the planet instead of bringing it all the way from Earth", In situ Resource Utilization (ISRU) can result in reduction of mass requirements for the exploration mission, reduction in mission risk and cost, and expanded human presence on the planetary surface. It can also enable the long-term commercial development of space by enabling low cost transportation, and providing the resources, technologies, and infrastructure required to allow commercial development activities to grow. Even though NASA currently does not have approved plans for human exploration missions beyond Low Earth Orbit, studies and mission design efforts and technology and system development activities are being pursued to develop technologies and mission concepts that can significantly reduce mission mass, cost, and risk and to enhance or enable robotic and human exploration initiatives. Key goals are to minimize the mass which must be brought from the Earth (including the equipment required to move or process the resource), minimize power consumption and Earth supplied processing consumables, enable or enhance new mission concepts not possible without the use of space resources, and develop infrastructure, resources, and products to promote the commercialization of space.

Proposals may be submitted for ISRU technologies at various destinations including the Moon, Mars, asteroids, planetary moons, etc. Areas for investigation of specific technologies for components or systems, and methods include the following:

- Digging, sorting, mineral separation, and transporting regolith or other materials to a processing reactor. Such systems should be lightweight, efficient, and capable of operating with minimal human supervision and maintenance.
- Extracting, collecting, and processing mission enabling or enhancing consumables (propellants, oxygen, etc.), or commercially viable resources and/or products from atmospheric, surface, and subsurface space resources that are power efficient, minimize the amount of equipment that must be brought from Earth, and require a minimum of Earth-supplied reagents. Emphasis should be placed on innovative designs and processes, and proposals for water/ice extraction or drilling should recognize the uncertainty and potential variability of both the location and abundance of such water.
- Processing surface materials into useful equipment (e.g., solar panels, radio antennas, replacement parts, etc.) which requires no further manufacturing or assembly.
- Extracting, processing, and manufacturing in situ materials that can be used for construction of products, habitable structures, and infrastructure on the Moon or Mars that enable long-term settlement.

H3 Space Utilities and Power

A key goal of the HEDS space utilities and power topic includes working with appropriate NASA and external organizations to identify and establish robust sources for abundant power for in-space and surface exploration systems for science discovery and the commercial development of space. A key objective is to drive down the cost of human/robotic exploration missions and campaigns. Some specific objectives include the following: (1) Development and validation of technology for a range of power levels and/or requirements, such as large space platforms, space transportation systems, including mobile, piloted or human-supporting lunar or planetary surface systems, and various other HEDS systems (e.g., habitats, extravehicular activity (EVA) systems, etc.). (2) Developing a foundation for the future testing and validation of key technologies and demonstrate innovative new human exploration and development of space systems concepts in space. (3) Establishing a foundation for profitable commercial development of space applications of these technologies in the mid- to far-term. Some of the specific technical objectives targeted by this topic include space solar power systems, space nuclear power systems for surface and in-space power applications, wireless power transmission systems, cryogenic propellant depots, and energy storage systems.

H3.01 Thermal Control Systems for Human Space Missions
Lead Center: JSC
Participating Center(s): MSFC

Thermal control is an essential part of any space vehicle as it provides the necessary thermal environment for the crew and equipment to operate efficiently during the mission. The requirements for human-rating and the specified temperature range (275 K - 310 K) drive the development of enabling active thermal control technologies to support human space exploration. A primary goal is to provide advanced thermal system technologies which are highly reliable and possess low mass, size and power requirements (i.e., reduced cost). Areas in which innovations are solicited include the following:

- Fault tolerant fluid-to-fluid heat exchangers that cannot fail in a way that permits leakage between fluid loops.
- Heat pumps to acquire waste heat at near 273 K and reject the heat above 300 K.
- Internal heat pumps or alternative technologies to provide cabin dehumidification on-orbit with a fluid heat sink of 288 to 298 K.
- Lightweight, flexible radiators which can be stowed compactly for transport and deployed for use.
- Micro-meteoroid tolerant and freeze/thaw tolerant radiators.
- Environmentally friendly, non-toxic single and two-phase working fluids that either freeze below 75 K or do not significantly change density upon freezing or thawing.
- Two-phase transport loops and associated controls which require low power for operations. Thermal energy storage systems.
- Controllable water evaporator heat rejection devices for use in vacuum environments.
- Microgravity compatible refrigerator/freezer technologies and/or system designs for food or scientific samples storage. Also, refrigerator/freezer technologies and/or system designs for long-duration planetary (partial gravity) usage.
- Low vibration or vibration isolating fluid components including fans, pumps, compressors, coolers, tubing, fittings, heat exchangers, and valves for use in microgravity processing applications.
- Highly accurate, remotely monitored, in situ, non-intrusive thermal instrumentation for meeting in-space science, manufacturing and safety needs.
- Materials and concepts for thermally efficient containment and processing of hazardous materials and samples in space.
- Advanced analytical tools for thermal design and analyses, which are amenable to concurrent engineering processes.
- Fluid quick disconnects that allow activation without exact alignment of the halves that have low activation force (approx. 10 lbf) with internal pressures of 500 psi, that are not sensitive to level 200 contamination, that leak less than 1x10-6 sccs He at 500 psia over a temperature range of –100 F to +100 F and that can be used with ammonia, water or R-134a.

Proposers should indicate explicitly how their research is expected to improve the mass, power, volume, safety, reliability, and/or design and analyses techniques for future thermal control systems for human space missions as compared to state-of-the-art technologies.

H3.02 Spaceport and In-Space Cryogenic Fluids, Handling, and Storage Technologies
Lead Center: KSC
Participating Center(s): GRC, JSC, MSFC

Advanced technologies are being solicited for cryogenic technologies for multiple aerospace applications. New and innovative techniques are desired in spaceport technologies, space environment applications, and extra-terrestrial applications (lunar and Mars environments). These focus areas include technologies that will increase the performance, operational efficiencies, safety, and reliability of cryogenic systems and provide for autonomous cryogenic operations in Earth, space and extraterrestrial environments.

Planetary Spaceport Cryogenic Fluids, Handling and Storage Technologies
Advanced technologies are being solicited for spaceport cryogenic systems for conditioning, storage, densification (sub-cooling) of cryogenic propellants and transfer and control to improve operational efficiencies, safety and reliability, and enable autonomous loading and off-loading operations. Planetary spaceports include Earth, Moon and Mars applications. Extraterrestrial spaceport systems have an added emphasis for lightweight and highly reliable characteristics. Specific areas of interest include the following:

- Cryogenic pumping systems that minimize thermal losses and can be utilized in liquid oxygen and/or liquid hydrogen and other cryogenic systems. These systems should possess high reliability and demonstrate ease of maintenance.
- New technology valves for cryogenic applications, including LOX, LH2, and LCH4 that minimize thermal losses and pressure drops across the component. Components should be adaptable to electromechanical activation and in a size range from 1/2 to 5 inches.
- Leak-proof compliant cryogenic quick disconnects that can be reliably mated, de-mated, and re-mated under misalignment (15 degrees for connectors 1-inch and larger) and dusty/windy conditions. Smaller connectors (1/4-inch to 1-inch) that require a low connecting force (for Mars applications) are critical. Reconnect issues that must be resolved include thermal (potential icing), sealing (surface damage due to environmental contamination), and cleanliness (potentially imposed by wind, etc.).
- Leak-proof, easy to use cryogenic couplings utilizing robust sealing technology that are compatible with cryogenic temperatures and liquid oxygen.
- New and innovative technologies to provide for propellant densification (sub-cooled LH2 and LOX). These technologies should provide for increased efficiencies and reduced costs associated in producing densified propellants.
- Recovery and storage system for gaseous hydrogen as vented from propellant storage (1000 gal/day) and/or during vehicle loading and drain-back operations (100,000 gal/day). Gaseous helium recovery (from hydrogen stream) is also desired.
- Propellant servicing mechanisms including umbilical alignment, latching, and release mechanisms which provide reliable and verifiable single and multiple connector mating, and enable autonomous loading operations. Integrated alignment and connection methods are desirable. Innovative latching technologies such as shape memory alloy applications and technologies that allow for maximum preload with minimal application loading are also desirable.
- A modular, reliable and cost effective oxygen and hydrogen production and liquefaction architecture are needed to enable production at an Earth based launch site. A modular system is desired to add/subtract capacity as needs fluctuate. Natural gas or coal as feedstock with a production ratio of 1 ton LH2 to 10 ton LOX is desired. The system may also produce electricity and LN2 (poly-generation plant). Modules that can be idle for extended periods and then brought on line quickly (48 hours or less) are also desired.
- Flowmeters and densitometers for measurement of densified, multi-phase cryogen at flowrates from 1.4 to 5.6 liter per second.
- Energy efficient, cost effective distribution systems for transfer of cryogens over long distances (up to several miles in distance).
- Low heat leak, lightweight, electromechanical shut-off valves for LO2 and LCH4 applications in size ranges from 1 to 1.5 inches.
- Cryocooler systems with cooling capacity greater than 10 watts operating in the 20-40 K range.
- Efficient LH2 storage systems for transporting LH2 to Mars and storage on the Martian surface.

In-Space Environment Cryogenic Fluids, Handling and Storage Technologies
Components or concept proposals are being solicited to improve the performance, operating efficiency, safety and reliability of cryogenic fluid storage and handling in a low gravity (10-6 g to 10-2 g) environment. Tanks of high energy propellant fluids, stored in their most efficient state (as low pressure sub-critical cryogenic fluids), are required for spacecraft and orbit transfer vehicle propulsion and power systems and space station life support. Generally, applications of this technology require long term storage (> 30 days), on-orbit fluid transfer and supply and unique instrumentation. Technology innovations are required in the following areas:

- Lightweight, low thermal conductivity cryogenic tanks strut and support concepts
- Low thermal conductivity cryogenic tank penetrations, i.e., instrumentation feed-throughs, feedlines, vent lines
- Lightweight, insulating, thermal protection schemes
- Robust insulation concepts for multiple launch/landing and ambient/vacuum pressure cycles
- Devices for vapor-free acquisition of cryogenic liquids
- Small, low power, lightweight (2 liter/minute) liquid oxygen transfer pumps
- Tank pressure control (e.g., thermodynamic vent) and/or integrated tank boil-off control and product liquefaction technologies
- Lightweight mechanical fittings and flex hoses with low heat leak
- Autonomous cryogenic disconnects and couplings
- Instrumentation for monitoring cryogens in low gravity including mass quantity gauging, liquid-vapor sensing and free surface imaging

H3.03 Spaceport/Range Instrumentation and Control Technologies
Lead Center: KSC
Participating Center(s): None

The goal of this subtopic is to develop instrumentation, systems and associated sensors required by Spaceports/Ranges to operate future generation space vehicles safely and efficiently. Technologies developed under this subtopic shall support the reduction of vehicle and payload cost per pound to orbit while increasing the safety of ground and flight operations by orders of magnitude.

The vision of the future is that multiple vehicles will be operating simultaneously in various phases of processing, launch, and landing from multiple terrestrial and planetary Spaceports/Ranges. In order to realize this, it will be necessary to have systems that integrate a suite of ground and space based sensors and instrumentation that provide the total Spaceports/Ranges solution. These systems need to be distributed and capable of supporting multiple sites and operational phases without reconfiguration. This will require autonomous knowledge based expert systems that can be implemented at multiple sites and require minimal infrastructure and personnel to operate.

This subtopic focuses on the development of sensors, instrumentation systems, meteorological and range technologies that uniquely suited to and used at Earth and planetary spaceports for processing, launch, tracking, controlling, and landing of space vehicles. The specific focuses are on sensors, transducers, instrumentation and systems that will be applied to the following areas:

Space Based Range
This focus area includes the development of technologies for satellite platforms or vehicles that provide remote sensing and instrumentation systems that perform or support the following functions: metric tracking, area surveillance, navigation aids, and atmospheric sensing. Each of these functions will require development of one or more of the following technologies; Integrated multi-, hyper-, and ultra-spectral instrumentation and sensors; Multi-channel transceivers. These will provide directors/controllers and vehicles vital real-time data that is necessary to interface with the National Airspace System for all phases of ascent and decent.

Decision Models and Simulation
New and innovative methods to ensure safe and cost effective real-time decision models that safely reduce conservatism and provide the necessary fidelity. Improvements in real-time computational capability and code development can significantly improve assessments. Specific technologies needed.

Range Dispersion Monitoring Instrumentation
Develop ground-based and airborne time-resolved real-time instruments to measure atmospheric chemical species associated with spaceport propellants and combustion products. Deployable instruments, both physical sampling and remote sensing, shall be capable of being networked to provide real-time data to a central processor for formatting and ingestion into a spaceport decision model. Sensors will be capable of identifying specific chemical species including hydrogen chloride, nitrogen dioxide, hydrazine (anhydrous, monomethyl, and unsymmetrical dimethyl), hydrocarbons, sulfur hexafluoride, and particulate matter.

Conflagration Decision Model: Heat and mass emission factors from solid propellant burning under water needs to be assessed and modeled. In addition to heat quenching, the chemical interaction of burning solid propellant and associated combustion products needs to be known as a function of water depth and salinity. The model output should yield mass and heat content of gaseous products including hydrogen chloride, solid products including particulate aluminum oxide and ammonium perchlorate, and liquid products including hydrochloric acid for unit mass of solid propellant involved, Unburnt propellant mass should also be assessed. Assessments are to be based on empirical studies using Space Shuttle-like solid propellants.

Decision Model On-Screen Editor
Develop methodology to enable on-screen editing of graphical outputs, such as meteorological parameters utilized in spaceport decision models. Shapes, slopes, and uncertainty bandwidths of curves should be automatically digitized based on operator on-screen inputs. This editing capability must allow the user to make changes to the forecasted toxic corridor in near real time. Methodology must execute with sufficient speed to accommodate user inputs, decision model re-evaluations, and input refinements to assess decisions, consequences, and uncertainties. Source code and executable code must be provided for inclusion in various spaceport decision models.

Knowledge-based Database
Develop and document a knowledge-based database with the capability to automatically maintain itself. This will include self-editing, error correction, and automatic formatting and filing of ingested data. The database will automatically poll the remote sensors on a given time schedule, evaluate the data and flag those sensors not responding with the correct data. Any data outside the preset parameters will be adjusted to a best fit, flagged and filed automatically.

Command, Control and Monitoring
New and Innovative technologies that include real-time advisory systems for the operator's and the user's; data reduction, analysis, and archiving; configuration validation and management; and low cost high fidelity training capabilities that minimize impact to operational systems. There is additional focus on sensors, transducers and instrumentation systems uniquely suited for instrumentation test beds to be characterized as payloads on Space Shuttle or other future space vehicle flights or Ground Support Equipment.

Miniature Mass Spectrometers for Hazardous Gas Detection
Development is needed for small, lightweight, rugged, inexpensive, mass spectrometers or other technology capable of measuring one part per million to 100 percent of hydrogen, helium, nitrogen, oxygen, and argon in a high-vibration environment. These instruments will be used on and around space launch vehicles for leak detection during ground processing, test firings, pre-launch propellant loading, launch, ascent, and descent (post reentry). The primary improvements in technology and performance over current instruments are size and weight reduction, cost reduction, and operation in a high vibration environment. Current instruments typically fill one or more equipment racks, weigh several hundred kilograms, and must be operated in an air conditioned, vibration free environment, typically several hundred feet from the potential leak locations. Their cost, size, and complexity mandate that each instrument must sample multiple leak locations on a time-shared basis. The target cost of an operational version of the desired instrument is $5,000-$20,000 each. The needed instrument accuracy is plus or minus ten parts per million or 5 percent of reading, whichever error is greater. The instrument should possess mass resolution capable of meeting the desired accuracy goals for hydrogen in the presence of 100 percent helium and for oxygen in the presence of 100 percent nitrogen. The instrument should be less than 3500 cubic centimeters total volume and have mass less than ten kilograms, including high-vacuum pump. The instrument should be able to withstand an 18 G vibration over a range of 5-2500 Hz. for 15 minutes on each axis without damage. The instrument should be capable of meeting the specified accuracy requirements for twelve hours without calibration. It should be capable of analyzing all five specified gases and providing the concentration of each within one second. While advances are primarily sought

in development of complete instruments, advances in key enabling technology such as vacuum pumps, ionizers, and detectors are also sought.

H3.04 Electromagnetic Physics Measurements, Control, and Simulation Technologies
Lead Center: KSC
Participating Center(s): None

Spacecraft launch operations involving toxic and explosive vapors and solid propellants as well as the operation of electronic components in space and in extra-terrestrial environments have created special concerns for understanding the electromagnetic dynamics of surfaces in contact with each other and the production of electrostatic charge due to this interaction. Specific interests for the 2001 solicitation include but are not limited to those listed below:

- Development of instrumentation to study the electromagnetic dynamics of surfaces in sliding contact with each other and its effects on the generation of electrostatic charge under a wide range of atmospheric conditions. Frictional contact between surfaces generates energetic electrons, ions, and photons. NASA is interested in instrumentation to measure the number and the type of the particles transferred as well the amount of mass transferred between surfaces after breaking contact. These instruments should be compact and light-weight and work under ultrahigh vacuum conditions (10-12 Torr).
- Development of dust generators that would deliver 1 to 40 mm uncharged particles at speeds ranging from 10 to 30 m/s at atmospheric pressures ranging from 100 mTorr to 760 Torr and at temperatures ranging from -100° C to 20° C.
- Develop techniques for measuring the charge-to-mass ratio and the speed of dry particles (1 to 100 mm) under high vacuum conditions (10-12 torr) over a broad range of temperatures. These techniques must be capable of supporting the future development of the electromagnetic characterization of materials during exposure to dust impingement in a vacuum, atmospheric, and non-terrestrial atmospheric environments.
- Develop improved triboelectric charge measurement and decay test devices that will become part of new testing standards for protective clothing and other materials to be used in space, extra-terrestrial and hazardous environments. Performance of the devices should be compared to similar data already collected by the Kennedy Space Center using existing technology. Proposals should focus on electric field detection equipment, digital scope electronics, air/gas ionization and motorized devices. Instruments and devices proposed for demonstration should be light weight, small in size, and suitable for operation in a vacuum with temperature ranges from -160° C (- 250° F) to 200° C (400° F), in various gaseous environments with pressures from 100 millitorr to 5000 torr and temperatures from -160° C (- 250° F) to 200° C (400° F) as well as terrestrial environments with temperatures from - 75° C (-100° F) to 65° C (150° F) and humidity from 10 percent to 100 percent. New concepts should give consideration to computer hardware and software to maximize capabilities to induce, detect, acquire, and record electric fields on material samples while plotting wave-forms in volts versus time.
- Development of miniature sensors for detecting and measuring the electric potential and charge distribution generated on spacecraft and landers. Developing software for modeling spacecraft and landers electric potentials based on previous flight experiment data and models.
- Develop cost-effective methods for ground based simulation of the environments of low Earth orbit space, deep space and planetary surfaces.

H3.05 Space Solar Power For Human Missions
Lead Center: MSFC
Participating Center(s): None

The goal of this activity is to conduct preliminary strategic technology research and development to enable large, multi-megawatt Space Solar Power (SSP) systems and wireless power transmission (WPT) for government missions and commercial markets (in-space and terrestrial). Dramatic advances in solar power generation (SPG) are needed for in space and surface use including systems for 50-100 kWe, 100-1000 kWe, and 1-10 MWe. These systems are required for large-scale space utilities and many transportation options. Solar power generation research and development required for collection of solar energy and conversion to electrical energy are critical to meet the low cost/specific mass goals for HEDS missions. Systems approaches for the utilization of SSP concepts and technologies, ranging from the near-term to the far-term, including systems concepts, architectures, technology, infrastructure (e.g., transportation), and economics have been modeled and refined under NASA’s Space SSP

Exploratory Research and Technology Program. Also, under the program technology research, development and demonstration activities to produce proof-of-concept validation of critical SSP elements for both nearer and farther-term applications have been conducted. Existing investments will be harvested for near-term demos, while multiple research and technology paths for large SSP systems will be pursued.

Goal
New technologies for enabling megawatt-class, low-mass, extremely high voltage solar arrays for large space solar power applications, including transportation vehicles, orbital facilities, and surface infrastructures.

Technology Elements
- Solar power generation
- Wireless power transmission
- Power management and distribution (PMAD)
- Energy storage
- Structures, materials and controls
- Thermal management and materials
- Robotic assembly, maintenance and operations

Objectives
- Develop advanced SSP concepts that incorporate the above listed technology elements
- Develop various SPG concepts including photovoltaic concentrator systems, solar thermal dynamic concentrator systems and thin film systems
- Integrate information on scores of technology options across several different systems concepts
- Perform tightly focused research and technology activities targeting all poles and promising system concepts
- Develop initial small-scale demonstrations of key SSP concepts and components using nearer-term technologies

Tasks
- Develop advanced SSP system technologies
- Undertake required/beneficial technology demonstrations (e.g., solar electric transportation applications, SPG, WPT, etc.)
- Conduct technology development work in the areas of SPG; WPT; PMAD; energy storage; structures, materials and controls; thermal management and materials; and robotic assembly, maintenance and operations

H3.06 Propellant Depots
Lead Center: MSFC
Participating Center(s): GRC

The focus of this subtopic is to develop and advance enabling technologies required to build and operate a propellant depot near Earth or in deep space. Cryogenic propellant storage depot technology is a unique area in that it has been studied in detail but little research has been accomplished in space, where the unique effects of low gravity come into play. The propellant depot will provide affordable propellants and similar consumables as needed in the development of space. A propellant depot not only requires technology development in key areas such as cryogenic storage or fluid transfer but in other areas such as lightweight structures, highly reliable connectors and autonomous operations. These technologies can be applicable to a broad range of propellant depot concepts or specific to a certain design. Specific areas of interest include:

- Electrolysis system that manufactures cryogenic propellants from water or ice in a low gravity environment. This system should incorporate innovative techniques and components to provide an automated, safe and highly reliable process.
- Water storage and transfer interface such as a bladder positive-expulsion system or other innovative techniques.
- Reliable and safe cryogenic storage for extended periods of time. This includes zero boil-off systems, advanced insulations and thermal control techniques such as vapor cooled shielding, systems utilizing the boil-off for drag make-up and innovative tank designs.
- Automated assembly, operations and maintenance. This includes cryogenic connects, disconnects and couplings; robotic assembly and repair; docking of large components; health monitoring and smart systems.

- Lightweight structures including inflatables, deployables and advanced composites.
- Micrometeoroid and space debris protection schemes and associated technologies including advanced lightweight materials, self-healing, integration with other structures and tankage and possible avoidance techniques.
- Associated propellant tank-set technologies including fluid slosh and orientation in low gravity environments, tank support structure dynamic interaction in orbit, support struts thermal performance, integrated insulation, instrumentation and plumbing penetrations and coating degradation.
- Schemes for warm tank chill down including spray nozzle configurations, liquid flow rate and duration, number of gas venting steps and performance in a low gravity environment.
- Stratification / hot spot management including mixing needs, mixing strategies and performance determination in low gravity environments.
- Low gravity performance and operating life determination of key components such as the liquid pumps, condensers, pressurization, liquid acquisition device, refrigerator and mass gauging instrumentation.
- Low heat leak valves and lines that are highly reliable with long life.
- Connects/disconnects with small or no fluid and heat leakage. The connects/disconnects should also have small pressure drops, small force and alignment requirements and long life with high reliability.
- Procedure for the capability for a no-vent fill with consideration given to micro-g condensation and fluid mixing.

Several options are available to test the technology needed for propellant depots. Technologies can be tested in the laboratory, on Expendable Launch Vehicles, the Space Shuttle, the ISS, a Small Scale Depot, or a Full Scale Depot. Laboratory testing can use sub- or full-scale tank sets for tests carried out on components, subsystems, and integrated systems on the ground. Identified improvements can be incorporated into subsequent tank sets, which may be used on the ground or in orbital tests. In some cases, a “proto-flight” approach may be used, where the original ground-test tank set can potentially be modified for subsequent testing on-orbit. For example, test requirements may be addressed by building a subscale experiment, which simulates the hydrogen fluid systems of the storage facility, evaluating their performance in a vacuum chamber, and then demonstrating micro-g fluid transfer by performing an orbital experiment.

H3.07 Space Nuclear Power For Human Missions
Lead Center: GRC
Participating Center(s): MSFC

Space Nuclear Power

NASA is interested in the development of highly advanced systems, subsystems and components for use with both nuclear reactors and radioisotopes for future robotic and manned missions. Principally, these systems of interest are non-nuclear; however, they may operate in close proximity to nuclear sources. Anticipated power levels range from 100’s of watts to multi-megawatts. Applications include: in-space primary propulsion, vehicle housekeeping, and science payloads, and on planetary surfaces; surface and atmospheric mobility, science stations, resource production, outposts and bases. Major technologies being pursued are:

- High efficiency power conversion > 20 percent, 2 kWe to MWe
- Low mass thermal management (radiators) < 6 kg/m2
- Electrical power management, control and distribution. > 1000 V, kWe to MWe

Supporting technology includes:

- High temperature materials/coatings > 1300 K
- Deployment systems Large radiators, surface mobility,
- Systems to mitigate planetary surface environments. (Dust, wind, planetary atmospheres, CO2, etc.)

In addition to overall system mass, volume and cost reductions, safety and reliability are of extreme importance. It is envisioned that these technologies will be used on robotic and eventually human missions, and it is to the Agency’s advantage to develop those technologies that transcend the robotic and human mission set with a minimum or re-design. Technologies that enable challenging missions such as bimodal nuclear thermal propulsion, high power nuclear electric propulsion and high power surface power are of particular interest. Technologies that are easily and efficiently scaled in power output and can be used in a host of applications (high commonality) are desired.

H4 Habitation and Bioastronautics

Technologies developed under this Topic are needed for the Advanced Human Support Technology Program (and other programs) to assure robust and reliable capabilities to support health and safety of human explorers during long-duration space missions. In addition, it is the goal of this topic to drive down the cost of human exploration missions and campaigns beyond Earth orbit and to develop and demonstrate critically needed capabilities for human activities in space. Some selected objectives of this topic include: (1) Developing innovative, affordable and highly operable new technologies for extra-vehicular activity (EVA) systems and advanced space habitation systems, and (2) Establishing a foundation for profitable commercial development of space applications of these technologies in the mid- to far-term.

H4.01 Extravehicular Activity Productivity
Lead Center: JSC
Participating Center(s): None

Advanced extravehicular activity (EVA) systems are necessary for the successful human exploration of all destinations beyond low Earth orbit. Complex missions to the Moon, Mars, L2, and other remote sites require innovative approaches for maximizing human productivity and for providing the capability to perform useful work tasks. Requirements include reduction of system hardware weight and volume; increased hardware reliability, durability, and operating lifetime (before resupply, recharge and maintenance, or replacement is necessary); reduced hardware and software costs; increased human comfort; and less-restrictive work performance capability in the space environment, in hazardous ground-level contaminated atmospheres, or in extreme ambient thermal environments. All proposed Phase I research must lead to specific Phase II experimental development that could be integrated into a functional EVA system. Areas in which innovations are solicited include the following:

Environmental Protection
- Passive and active radiation protection technologies that protect the suited crewmember from radiation particles.
- Dust and abrasion protection materials to exclude dust and withstand abrasion.

EVA Mobility
- Nonmetallic low profile space suit bearings that maximize rotation and mobility and are also lightweight and low cost.

Life Support System
- High-capacity oxygen storage, supply and recharge systems for normal and emergency supply of oxygen for breathing.
- Low-venting or non-venting regenerable individual life support subsystem(s) concepts for crewmember cooling, heat rejection, and removal of expired water vapor and carbon dioxide.
- Fuel cell technology that can provide compact high-energy power to a space suit.
- Convection and freezable radiators that will be low cost and weight for thermal control.
- Space water membrane evaporators for a space suit.
- Variable conductance flexible external suit garment that can function as a radiator for high metabolic loads and as an insulator for low metabolic loads.
- Extremely thermal conductive fibers or other alternatives to water-cooling loop tubing.

Sensors/Communications/Cameras
- Space suit mounted displays for use both inside and outside of the spacesuit. Outside mounted displays must be low profile and compatible with space environment. Internal displays must be 100 percent O_2 safe, unobtrusive and ultimately project onto the helmet visor.
- IR camera that displays temperature of environment for safe handling of objects, geology science support and are integratible onto a spacesuit or rover.

Integration
- Robotics and display interface software that permit autonomous voice control via suited EVA crew.
- Minimum gas loss and low power airlock providing quick exit and entry, and can accommodate an incapacitated crewmember.
- Light weight, non-metallic; environmentally harden manual or powered tools for driving fasteners.
- Innovative self-locking, multi-use captive fasteners. Tether hooks for equipment or crewmembers.
- Low profile, low power and flexible body/limb mobility sensors, signal conditioners and software for immediate data analysis display. Will be used internally or externally for space suit garment quantitative mobility testing.

H4.02 Advanced Habitation Systems
Lead Center: JSC
Participating Center(s): None

Advanced habitation technology is sought to enable Human Exploration and Development of Space Enterprise future orbital, planetary and deep space applications. Space and planetary habitation, pressure structures and unpressurized shelters are being sought out to provide innovative structural solutions that combine high strength and light weight materials along with the reliability, durability, reparability, radiation protection, packaging efficiency and life-cycle cost effectiveness. Advances in material developments and manufacturing techniques that enable the structure to "self-heal" and the emplacement, erection, deployment or manufacturing of habitats in space or on the Moon and Mars are considered enabling technologies for the evolution of humans into space and the eventual settlement on Mars. Integration of sensors, circuitry and automated components to enable self-deployment and "smart" structures are considered necessary for the habitat to operate autonomously. The objective is to create an advanced habitat that becomes a "living" structure that not only runs autonomously, but also has self-healing capability. A number of technologies and techniques have been proposed that allow the delivery of deployable habitats to space and planet surfaces or the manufacturing and construction of habitats on planet surfaces. These include:

- Underground development of habitable structures that meet human space flight requirements.
- Design, manufacturing and testing of inflatable structures that meet human space flight requirements.
- Manufacturing in situ (Moon and Mars) structures for autonomously developing habitats that meet human space flight requirements.
- Techniques for fully integrated skin and sensors/circuitry that enables "smart" structures that autonomously detect, analyze, and correct (repair) structural failure.
- Integrating miniaturization technology into the habitat skin, thus reducing weight and increasing self-autonomy.

Quantitative assessments require innovative, space flight compatible habitat structures that meet the needs for human space flight and structural integrity. The Moon and Mars are of the most interest. Consideration of flight-testing in space or at the Moon should be considered. Areas in which innovations are solicited include the following technologies for use in space (zero gravity) and/or the planetary surfaces:

Habitat Structures
- Advanced metal alloy structures
- Advanced composite structures
- Advanced inflatable structures
- Advanced planetary in situ derived structures

External Environment Protection
- Radiation
- Micrometeoroid / Orbital Debris / Blast Ejecta
- Vibration and Noise
- UV, AO, Thermal
- Dust, chemical contamination, self-healing

Integrated Habitation Systems
- Smart Habitats
- Integrated Detection, Monitoring and Control
- Internal Systems and Outfitting
- Advanced Habitat Evolution

Logistics, Maintenance and Repair
- Logistics Supply, Storage and Recycling
- Automated Servicing and Repair
- Contamination Control and Housekeeping

H5 Space Assembly, Inspection and Maintenance

One goal of the space assembly, inspection and maintenance topic is to enable a much more robust set of options for affordable implementation of ambitious new modular space exploration systems and missions. Another goal is to drive down the cost of human exploration missions and campaigns beyond low Earth orbit. Objectives. The objectives of this topic include the following: (1) Developing and validating technologies for the space assembly of large systems -- including both science mission systems (e.g., observatories) and human operational systems. (2) Enabling autonomous and/or tele-presence systems inspection. (3) Advancing remote or shared control of these capabilities in near-Earth and interplanetary space. (4) Developing and validating the capability to extend the life and reduce the costs if a new generation of space systems through repair, refueling, upgrades and re-use of components from one system to another. (5) Minimizing the impact of space system failures by enabling easy access for repair -- thus reducing system-level functional redundancy (and associated costs). (6) Enabling a reduction in the total mass launched to orbit for given mission architectures. (7) Establishing a foundation for profitable commercial development of space applications of these technologies in the mid- to far-term

H5.01 Automated Rendezvous, Docking and Capture
Lead Center: JSC
Participating Center(s): GSFC, MSFC

In support of future robotic and human missions beyond low Earth orbit, the need for automated rendezvous and docking has been identified. This subtopic addresses hardware and software technologies necessary to develop a robust automated guidance, navigation, and control (GN&C) capability bringing together two vehicles from initially large distances (> 1000 kilometers) around a remote planet and docking them. The “target” vehicle may be orbiting the planet for several years prior to the rendezvous. The “chaser” vehicle may begin the rendezvous after completing orbital insertion from an interplanetary cruise phase or after launching from the surface of the planet.

Because of intended use for future human missions, the rendezvous and docking capability must be low risk ensuring a very high level of mission success. The proposed system should be modular and adaptable to smaller robotic missions in order to validate the technology and spread the investment and experience base.

Innovations are sought to solve the following technology challenges:

- Spacecraft self-determination of orbits around remote astronomical bodies (including the Moon and Mars at a minimum) and supporting the initial phase of rendezvous operations when spacecraft to spacecraft ranges are possibly very large. Innovative technologies may include ground terrain tracking methodologies or possibly deployment of land based or orbiting nav and communication aids when cost effective or necessary. Alternative strategies are additionally sought.
- A minimum relative navigation sensor suite addressing spacecraft-to-spacecraft ranges of 100 kilometers through docking including relative attitude control during the final 100 meters of the approach.

H5.02 Robotics Assistance, Assembly, Maintenance, and Servicing
Lead Center: JSC
Participating Center(s): KSC

Proposals are solicited for innovative concepts that improve robotic capabilities as well as the human's ability to interact with and control robotic systems while minimizing the workload to EVA and IVA astronauts as well as ground operators.

Robotic Manipulators, End-Effectors, and Joints
Proposals are sought which include improvements to robotic joints, actuators, end-effectors, tools, and mechanisms. Proposals should address issues associated with space compatibility. Specific areas of interest include the following:

Technologies or systems that provide a reduction to the weight and or volume of robotic systems such as:

- Reduced scale high power-to-weight ratio actuators including but not limited to magnestostrictive motors and synthetic muscles
- Miniaturized actuator control and drive electronics
- Miniaturized sensing systems for manipulator position, rate, acceleration, force and torque

Robotic systems that accommodate existing EVA tools including but not limited to anthropomorphic systems and multi-fingered dexterous end-effectors.

Planetary robotic mobility systems and devices; robots will be needed to work with and to transport humans and equipment on a planetary surface. Examples include novel rover drive systems, suspension systems, and manipulator systems.

Compact low power devices for site setup, operation, and planetary surface exploration. Novel mechanisms are needed to enable human exploration and habitation of planetary bodies. Examples include site clearing and setup devices, equipment deployment devices, sample collection and manipulation devices, and the actuation components for these devices.

Human/Robotic Interface
Proposals that improve operator efficiency via advanced displays, controls and telepresence interfaces and improve the ability of humans and computers to seamlessly control robotic systems are sought. Specific technology requirements include the following:

- Tactile feedback devices that provide operator awareness of contact between work space objects and the robot structure. Key aspects of this technology are ergonomics and safety.
- Force feedback devices that provide operator awareness of manipulator and payload inertia, gripping force, and forces and moments due to contact with external objects. Key aspects of this technology are ergonomics and safety.
- Stereographic display systems that provide high-fidelity depth perception, field of view, and high resolution.
- Tracking position and orientation of user appendages (i.e., head, arms, fingers, eyes) for the purpose of providing motion commands to the robot. Key aspects of this technology are to free the operator of any exoskeletons or devices attached to the body which impede or restrict the operator's movements.
- Innovative miniaturized display hardware for use with Helmet Mounted Display (HMD) systems that project data in a Head Up Display (HUD) format. Emphasis is placed on compact, low mass hardware that can be used with HMD displays and efficiently display data (graphical and alphanumeric) without detracting from the HMD displayed video.

Intelligent Autonomous Systems
- Artificial intelligence based systems and architectures with provision for crew oversight.

Proposals are solicited for innovative concepts which will increase the functionality and robustness of extravehicular robotic (EVR) systems for science and operations. One example of such a robot is an EVA Robotic Assistant for planetary surface exploration. This robot should be able to follow a geologist, carry his tools and samples, provide video documentation of his activities plus real-time video for remote viewing and be commandable via a combination of gesture/voice by the geologist. Innovative concepts in machine vision, as well as in other non-vision forms of sensing and perception, which can provide the necessary input for the robotic system to function under a wide variety of operating conditions are required. Some specific technology needs to enable this EVA Robotic Assistant are:

- Small, low power machine vision systems for tracking a moving, articulated object such as a geologist exploring a planetary surface on foot. The tracker should not encumber the geologist by requiring him to wear special targets or beacons.
- Aided dead-reckoning and landmark navigation to keep a record, referenced to the terrain, of where the geologist is now and where he has been. Systems which do not require emplacement of external beacons are needed.
- Machine vision techniques for real-time image registration to create mosaics suitable for human viewing are needed. Mosaic construction must take into account camera motion and changes in lighting over extended periods of either several hours of EVA activity or a subsequent return to a previously visited location. This is intended to let the crew back in the habitat see what the geologist sees or to look around as if they were there.

Another example of an EVR is a mobile, remotely controlled video camera platform capable of transmitting video to its operator. For planetary surface exploration, this could be a scout intended to locate sites for follow-up EVA. For in-space operations, this could be an AERCam used to provide video views of the exterior of the International Space Station or a future Space Solar Power Satellite to inspect for damage, plan or supervise repair work, etc. Specific technology needs include:

- Supervised and traded control systems which allow for seamless human/robot interaction. The ability to accommodate both planned and unplanned human and autonomous operations within a task is essential.
- Model based landmark navigation to allow a mobile camera platform to find its way around the outside of a large satellite without requiring the addition of expensive external beacons including the ability to update the model of the satellite exterior as it changes.
- Machine vision techniques, including the construction of image mosaics, for detection of unspecified changes in objects being inspected under changing lighting and viewing conditions.
- Virtual reality interfaces that make it practical to operate such a robotic camera platform in close proximity to a large satellite when the operator has the view from the camera platform but no views of the platform.

H6 Human Exploration and Expeditions

The goals of this topic include: working collaboratively with technology developments in Space Science (and other organizations) to enable future human exploration missions to effectively address -- and at a fundamental level -- the "grand" science challenges facing NASA, driving down the cost of human exploration missions and campaigns beyond Earth orbit, and sharing the experience of exploration with the public. In pursuing these goals, the objectives under this topic include: 1) Developing and validating the capability for human explorers to gain deep lunar and planetary sub-surface knowledge and access -- both remotely and through sampling -- ranging down to 1000s of meters. 2) Enabling safe and affordable human exploration of other planetary surfaces -- locally but over global distances involving traverses of up to 1000s of kilometers. 3) Integrating and validating the technologies needed to revolutionize public engagement in "virtual exploration" -- ranging from higher rate communications, to the creation of virtual reality simulations, to innovative human-machine interfaces. 4) Establishing a foundation for profitable commercial development of space applications of these technologies in the mid- to far-term.

H6.01 Automated Exploration Applications of Intelligent Systems
Lead Center: ARC
Participating Center(s): JSC, MSFC

NASA is planning to fill space with robotic explorers, carrying our intelligence and our curiosity outward in ways never before possible. To survive decades of operation, these remote agents need to be smart, adaptable, curious, wary, and self-reliant in harsh and unpredictable environments. NASA is soliciting research in automated reasoning for autonomous systems that will enable the design, construction and operation of a new generation of remote agents that perform progressively more exploration at much lower cost than traditional approaches. NASA also needs automated reasoning to improve its operations closer to home. For instance, software is needed for monitoring shuttle and space station systems and diagnosing faults when they occur or software agents for processing, classifying and archiving the mountains of data from Earth orbiting satellites. Specific areas of interest for automated reasoning include the following:

Agent Architectures
- Autonomy architectures that support plug and play of automated reasoning components
- Architectures for homogeneous and heterogeneous distributed systems of agents Capabilities related to Autonomous Performance
- Planning and scheduling systems that support planning concurrent with execution, plan optimization, resource management and/or distributed plan creation capabilities
- Model-based and statistical methods for monitoring, command confirmation, fault isolation, and diagnosis from sensor information
- Methods for robust recovery and repair
- Algorithms for real-time deduction and search
- Novel environment sensing or mapping capabilities
- Machine learning and adaptive control technologies
- Methods for precisely and dynamically adjusting the level of human control

Capabilities Related to Design
- Declarative specification of software and hardware behaviors, collaborative environments for large scale model building
- Methods for code synthesis and controller generation from declarative specifications
- Automated generation of test sequences from component models and analytic verification methods, including model checking and theorem proving
- Methods for modeling, code synthesis, simulation, testing and validation, as above, that operate from hybrid discrete/continuous models

H6.02 Flight/Ground Operations and Crew Training
Lead Center: JSC
Participating Center(s): MSFC

Dramatic improvements will be needed in crew and ground operations performance and productivity as NASA develops new operational capabilities to support multiple, manned missions and long duration and long distance missions. Robotic, vehicle and support systems will be required to be more robust, autonomous and intelligent as well as more maintainable. These capabilities will allow operators to "buy time" by increasing system mean time between failures, predicting when intervention will be needed, managing degraded operations, and using functional redundancy. Advanced capabilities for information, data analysis, presentation, onboard planning, execution and fault management will be needed to assist the crew. Sophisticated training, maintenance support systems and a robust knowledge base will be needed onboard, and will need to be well integrated with increasingly advanced control and maintenance systems. Ground support operations will need to be redesigned to support the increasing autonomy of space systems and onboard crew. There will need to be advanced support for distributed and adjustable command responsibility and distributed and flexible training. Significantly, more productive and intuitive approaches are needed for updating, adapting, testing and certifying advanced distributed operations software and knowledge bases during missions. Specific areas of interest in the areas of crew training and in flight and ground operations include:

Crew Training and Maintenance Support Systems
- Flexible training and tutoring systems for mission operations support including distributed cooperative training, virtual reality training, intelligent computer-based training, and authoring tools
- Integration of training with advanced control and maintenance systems
- Tools to collect/capture and tailor design-time information for use in developing training materials
- Procedures or technology for evaluating effectiveness of innovative training methods

- Data Management, Data Analysis, and Presentation and Human Interaction
- Methods for selecting and summarizing vehicle systems and payload data relating to status and events to support crew and ground awareness, operational decision-making, and management by exception and opportunity rather than by continuous or scheduled monitoring
- Human interaction methods for collaboration, cooperation and supervision of intelligent semi-autonomous systems
- Goal-driven collaborative data analysis systems capable of adaptation and learning
- Simple systems for notification and coordination including natural language interfaces
- Immersive environments: real-time environments to enhance a human operator's ability to interact with large quantities of complex data, especially at distant locations
- Intelligent data analysis techniques: capabilities to interpret, explain, explore, and classify large quantities of heterogeneous data

Robust Planning, Operations, Fault Detection, and Recovery with Distributed Adjustable Command Responsibility

- Onboard planning, sequencing, monitoring, and re-planning of activities including systems and crew activities
- Flexible management of the actions of subsystems within the larger context of system flight rules and constraints
- Flexible and robust fault management approaches that use system models, "buy time" for human intervention and maintenance, and learn from human operators during and after the interventions
- Approaches to distributed and adjustable command responsibilities among systems, crew and ground
- Model-based continuous estimation of the likelihood of critical events, including human errors, to provide warnings of potential events and their consequences and to suggest appropriate countermeasures
- Integration of systems for fault management, maintenance and training
- Operations knowledge management and software updating
- Systems and processes for crew and ground operators to quickly and effectively define, update, test and certify operational knowledge and rule bases before and during missions designed for reuse in autonomous systems and in training
- Tools for incorporating and using engineering data and specifications (about equipment and its operating modes and failures and about operations procedures) into operations knowledge and model-based autonomous systems
- Tools and environments to support modification and validation of knowledge bases (models of activities, equipment and environment) in intelligent autonomous software by operators to capture methods and knowledge used by operators during interventions and to collaboratively adapt to unanticipated circumstances
- Simulation environments and tools for use in designing and testing intelligent semi-autonomous systems

H7 Space Transportation

The goal of the HEDS Space Transportation topic is to identify and to develop specific new space transportation technologies that can significantly increase the safety and reliability of ambitious, future human exploration missions and campaigns beyond Earth orbit while dramatically reducing the transportation-related cost of human exploration initial missions and sustained campaigns. This includes both systems and infrastructures associated with Earth-to-orbit transportation, in-space transport, and excursions from space to and from targets in space (including the Moon, Mars and asteroids). The objectives under this topic include: (1) Developing and demonstrating selected, highly innovative technologies needed to assure that future human exploration space transportation systems and infrastructures are safe and "robustly" reliable. (2) Developing and validating technologies for the affordable transportation to - and from - targets in space beyond low Earth orbit. (3) Enabling reliable and affordable transportation to all points of interest globally on the Moon or Mars. (4) Establishing a foundation for profitable commercial development of space applications of these technologies in the mid- to far-term.

H7.01 Test and Validation Management Methodologies
Lead Center: SSC
Participating Center(s): None

Proposals are solicited for innovative methods and approaches to management of test and validation of space transportation technologies. Proposals should address methods of providing more cost efficient, effective identification and use of test and validation facilities or the development of key test and validation technologies that can improve reliability and performance of test and validation facilities and operations. Specific areas of interest in this subtopic include the following:

Application of System Science to Management of Test and Validation
New innovative technologies and approaches to incorporating knowledge and information processing techniques (intelligent systems, data mining techniques, fuzzy logic, neural nets, optimization techniques, etc.) to support decision making for test and validation management.

- Data mining and optimization techniques that will provide identification and analysis of test and validation facilities for selection of the best facility.
- Modeling and analysis methods to identify and evaluate technical areas required to be developed or modified to provide effective testing and validation of space transportation technology.
- Modeling and analysis methods to identify and assess areas for improving test efficiencies and/or reducing operational costs for the test and validation of the technology.
- Techniques to reduce required sample size to maintain acceptable levels of confidence in cost data.
- Risk management techniques.

Methods for Improvements in Test and Validation Operations, Safety and Reliability
Identification and development of specific technologies that will provide improved effectiveness and efficiency in the operation, safety, and reliability in all test and validation programs.

- Software and hardware systems that create a virtual test and control system to monitor operations and data analysis. This virtual control system would incorporate expert base and information processing techniques that provide for real time interactive decision making.
- Graphical data software to provide a near real time data translation into 2-D or 3-D graphic display that provides a visual representation of the physical characteristics of the data, facilitating the data analysis.
- Interface hardware and software that provide for Network Appliance technology to be applied to test operations.
- Develop design concepts for optimized, and/or modularized, test and validation facilities which will improve test efficiency and reduce transition time between test articles.

H7.02 High Power Electric Propulsion For Human Missions
Lead Center: GRC
Participating Center(s): None

High-power (> 100 kW), electric propulsion technologies are a critical component of orbit transfer and planetary insertion in the HEDS missions. High-power electric propulsion can reduce propellant mass requirements (compared to all-chemical propulsion) to the extent where it allows a reduction in launch vehicle class or an increase in payload. In either case, the mass savings result in significant cost savings for HEDS missions. For interplanetary missions, high-power electric propulsion will provide quicker trip times (depending on available power) than all-chemical propulsion since its high specific impulse (Isp) allows for direct transit to planetary bodies.

Innovations in high-power electric propulsion technology are sought that will increase high-power electric thruster efficiency, increase thruster life, reduce total system mass, reduce system complexity, and reduce trip time. Thruster parameters of interest include power levels of 100-kW to several megawatts; Isp values of 2000 s for Earth-orbit transfers to over 5000 s for planetary missions; thruster efficiencies in excess of 50 percent; and system lifetimes commensurate with mission requirements (typically 10,000 hours of operation). Proposals that seek to investigate and resolve, either theoretically or experimentally, the fundamental lifetime and performance limiting mechanisms of high-power electric thrusters are of particular interest.

Several propulsion devices are being considered for high-power HEDS missions including Hall, Ion, magnetoplasmadynamic (MPD) thrusters, pulsed inductive thrusters (PIT), and VASMIR. The specific technology challenges for high-power propulsion devices include:

Hall and Ion
- Scaled up in power (100 kW class)
- Use of alternate propellants such as krypton or argon
- Maintain high efficiency of today's lower power systems (> 55 to 70 percent efficient)
- Long lifetimes (> 10,000 hours)

MPD
- Long lifetime components > 10,000 hours
- Improved efficiency (> 60 percent)
- Simpler, higher efficient, continuous (not pulsed) power processing systems (> 90 percent)
- Lighter thermal control (most of the inefficiency results in waste heat not removed by the exhaust, e.g., almost 400 kW of heat must be removed for a 1 MW MPD) (< 2 kg/kWt)

Pulsed Inductive Thrusters
- High efficiency > 60 percent
- Simple, efficient and light pulsed power processing systems (> 90 percent, < 1 kg/kW)

VASMIR
- High efficiency stages and processes (total efficiency > 60 percent)
- Light components including superconducting magnets
- Advanced, long-term fuel storage (e.g., hydrogen and helium) [years on-orbit, < 20 percent tankage]

Specific Impulse Throttling
- Techniques to allow for throttling of Isp at constant power (~2500 sec to 10,000 sec)
- Other innovative propulsion concepts providing the above Isp's, > 60 percent efficiency, at power levels from 100 kW to multi-megawatts

Support Systems
- Light, inexpensive, throttleable propellant feed systems for various fuels
- Radiation-resistant components to resist cosmic and power system radiation
- Safety and redundant systems to ensure crew member safety and mission success
- Gimbaling systems: (2DOF > +/- 20^o)

8.1.5 SPACE SCIENCE

The space science technology development program develops and makes available new space technologies needed to enable and enhance exploration, expand our knowledge of the universe, and ensure continued national scientific, technical, and economic leadership. It strives to improve reliability and mission safety, and to accelerate mission development. Since the early 1990s, the average space science mission development time has been reduced from over nine years to five years or less, partly by integration and early infusion of advanced technologies into missions. For missions planned through 2004, we hope to further reduce development time to less than four years. Our technology program encompasses three primary goals. First, we develop new and better technical approaches and capabilities. Then we validate these capabilities, in space where necessary, so that they can be confidently applied to space science flight projects. Finally, we apply these improved and demonstrated capabilities in the space science programs and transfer them to U.S. industry for public use through programs such as the Small Business Innovation Research Program. For more information on space science at NASA, see http://spacescience.nasa.gov/strategy/2000/

S1 Sun Earth Connection

The goal of the Sun-Earth Connection (SEC) Theme in the Space Science Enterprise is an understanding of the changing Sun and its effects on the Solar System, life, and society. SEC's strategy for understanding this interactive system is organized around four fundamental quests designed to answer the following questions: 1) Why does the sun vary? 2) How do the planets respond to solar variations? 3) How do the sun and galaxy interact? 4) How does solar variability affect life and society? SEC's challenging science program involves: 1) Seeking breakthroughs in understanding by making measurements from new vantage points within and outside the Solar System. 2) Making simultaneous, system-wide measurements with constellations of spacecraft that resolve existing space-time ambiguities. 3) Applying new scientific knowledge strategically to produce direct and immediate benefits to our increasingly space-dependent society.

S1.01 Particles and Fields Measurements for Missions to the Heliosphere, Planetary Magnetospheres and Upper Atmospheres
Lead Center: GSFC
Participating Center(s): JPL

The Sun-Earth Connection theme studies the Sun with its surrounding heliosphere carrying its photon and particle emissions and the subsequent responses of the Earth and planets. This requires remote and in situ sensing of upper atmospheres and ionospheres, magnetospheres and interfaces with the solar wind, the heliosphere, and the Sun. Improving our knowledge and understanding of these questions requires accurate in situ measurements of the composition, flow, and thermodynamic state of space plasmas and their interactions with atmospheres as well as the physics and chemistry of the upper atmosphere/ ionosphere systems. Remote sensing of photons and neutral atoms are required for the physics and chemistry of the Sun, the heliosphere, magnetospheres, and planetary atmospheres and ionospheres. Photon measurements are covered under other subtopics (e.g., S1.06, S2.01, and E1.01). Since instrumentation is severely constrained by spacecraft resources, miniaturization, low power consumption and autonomy are common technological challenges across this entire category of sensors. Specific technologies are sought in the following categories:

Plasma Remote Sensing (e.g., neutral atom cameras)
- Advanced neutral atom imagers for energies from a few eV to 100 keV to remotely sense ion populations in the heliosphere and in the magnetospheres of the planets. This may involve techniques for high-efficiency and robust imaging of energetic neutral atoms covering any part of the energy spectrum from 1 eV to 100 keV.

In Situ Plasma Sensors
- Improved techniques for imaging of charged particle (electrons and ions) velocity distributions.
- Improved techniques for the regulation of spacecraft floating potential near the local plasma potential, with minimal impacts on the ambient plasma and field environment.
- Low power digital time-of-flight analyzer chips and waveform generators with sub-nanosecond resolution and multiple channels of parallel processing.
- Miniaturized, radiation-tolerant, autonomous electronic systems for the above.

Fields Sensors
- Improved techniques for measurement of plasma floating potential and DC electric field (and by extension the plasma drift velocity), especially in the direction parallel to the spin axis of a spinning spacecraft.
- Measurement of the gradient of the electric field in space around a single spacecraft or cluster of spacecraft.
- Improved techniques for the measurement of the gradients (curl) of the magnetic field in space local to a single spacecraft or group of spacecraft.
- Direct measurement of the local electric current density at spatial and time resolutions typical of space plasma structures such as shocks, magnetopauses, and auroral arcs.
- Miniaturized, radiation-tolerant and autonomous electronic systems for the above.

Electromagnetic Radiation Sensors
- Radar sounding and echo imaging of plasma density and field structures from orbiting spacecraft.

S1.02 Solar Sails
Lead Center: JPL
Participating Center(s): GSFC, LaRC, MSFC

The objective of this subtopic is to stimulate breakthroughs in technologies associated with solar sails. Solar sails are envisioned as a low-cost, efficient transport system for future deep space missions. They are baselined for several strategic missions in the Sun-Earth Connection (SEC) Space Science theme, including Solar Polar Imager and Interstellar Probe, the latter being a solar sail mission to explore interstellar space. Missions in the Exploration of the Solar System (ESS) theme would be broadly enhanced by the availability of proven, solar sail technology. Areas in which innovations are sought include lowering the cost of sail development and application, enhancing sail delivery performance, and reducing the risks associated with sail development and application.

Technology innovations are sought in the following areas: packaging and deployment, materials, structure/systems, fabrication, system control (attitude, etc.), maneuver/navigation, operations, durability/survivability, and sail impact on science.

Three parameters have been used as sail performance metrics in mission applications that imply levels of technology capability: sail size, sail survivability for close solar approaches, and areal density (ratio of mass of the sail to area of the sail). In addition, overall system metrics are cost, benefit, and risk. Technologies of interest should be geared toward a wide range of sail sizes, solar closest approach distances, and areal densities, and may be optimized for one portion of the range rather than trying to cover the whole range. Sail sizes may range from very small (meter-sized for use with tiny payloads or use as auxiliary propulsion), to medium (50-100 m size for achieving high-inclination solar orbits) and ultimately to the very large (hundreds of meters for leviated orbits, high delta V, and for use in leaving solar system at high speed). Closest solar approaches may range from 1 AU down to 0.1 AU. Areal densities for a solar sail subsystem (excluding payload) may range from 0.1 to 10 g/m^2.

S1.03 Multifunctional Structure and Sensor Systems
Lead Center: JPL
Participating Center(s): GSFC, LaRC

NASA seeks innovative concepts for multifunctional or integrated structure and sensor/electronic systems to reduce spacecraft size and mass, and to enable lower-cost and more capable aerospace vehicles, instruments and structures. A multifunctional system combines several functions, which are usually performed by separate subsystems, into a single highly integrated system. Additionally, multifunctional systems would enable more effective health monitoring where, in this case, "health monitoring" refers to the state of the spacecraft, subsystem or structure. To achieve this will require revolutionary advances over the capabilities of traditional spacecraft systems. Microspacecraft systems (as small as 10 kg, using 10 W, or less) of all varieties will enable new missions that are currently impractical. These systems will include, but are not limited to, orbiters, landers, atmospheric probes, rovers, penetrators, aerobots (balloons), planetary aircraft, subsurface vehicles (ice/soil), and submarines. Also of interest are distributed sensor systems integral with structural elements for the monitoring of the state of those elements or for the construction of new classes of scientific instruments based upon the unique features of the integrated system. New technologies are needed in the areas of integration and packaging of MEMS sensors and actuators integral with advanced lightweight materials for structure and propulsion or thermal control.

Potential mission applications for the technology products developed in this area include micro/nano-spacecraft, thin-film gossamer spacecraft, adaptive large-aperture telescopes, antennas, and airframes. High-priority technology development needs are:

- Techniques for the structural integration of low-volume electronics packaging such as chip-on-structure, chip-on-flex (flexible substrate), and imbedded electronics.
- Concepts for integrating electronics, MEMS, power distribution, energy storage, thermal management, and radiation shielding with ultra-lightweight composite structures.
- Multifunctional membranes that incorporate thin-film electronics and MEMS sensors, photovoltaic cells, or electrochromic materials.
- Adaptive and reconfigurable structures that can respond reactively to environmental stimuli for self-repair of damage.

- Avionics, including highly integrated "systems-on-a-chip" technologies that integrate areas such as telecommunications, power management, data processing and storage, on-chip energy storage, on-chip magnetics or data sensors with structure and/or actuators.
- Micro-Electro-Mechanical Systems (MEMS) including: microactuation, navigation sensors, health-monitor sensor systems, low power and low-mass on-chip communication systems, and micro fluid storage and control systems.
- Thermal management, including active and passive techniques.
- Integration of functions such as engineering sensors and science instruments, structure, thermal, cabling, propulsion, etc.
- Technology for integrating three-dimensional VLSI, chip stacking, multi-chip-module stacking and other advanced packaging techniques with structural elements.
- Concepts and designs for test and validation of design integrity and performance of IP based ASICs, mixed signal ASICs and MEMS.

S1.04 Spacecraft Technology for Micro/Nanosats
Lead Center: GSFC
Participating Center(s): None

NASA seeks research & development of components, subsystems and systems that enable inexpensive, highly capable small spacecraft for future SEC missions. The proposed technology must be compatible with spacecraft somewhere within the Micro/Nano range from 100 kg down to 1 kg. All proposed technology must have a potential for providing a function at current performance levels with significantly reduced mass, power, and cost, or, have a potential for significant increase in performance without additional mass, power and cost. These reduction and/or improvement factors should be significant and show a minimum factor of 2 (relative to the state of the art in 2000) with a goal of 10 or higher.

A proposed technology must state the type or types of expected improvements, (performance, mass, power, cost), list the assumptions for current state of the art, and indicate the spacecraft range of sizes for which the technology is applicable.

The integration of multiple components into functional units and subsystems is desirable but not a requirement for consideration.

- Avionics and architectures that support command and data handling functions, including input/output, formatting, encoding, processing, storage, and A to D conversion. System level architecture, software operating systems, low voltage logic switching, radiation-tolerant design and packaging techniques are also appropriate technologies for consideration.
- Sensors and actuators that support guidance, navigation, and control functions such as sun/earth sensors, star trackers, inertial reference units, navigation receivers, magnetometers, reaction wheels, magnetic torquers, and attitude thrusters. Technologies with applications to either spinning or three-axis stable spacecraft are sought.
- Power system elements including those that support the generation, storage, conversion, distribution, regulation, isolation, and switching functions for spacecraft power. System level architecture, low voltage buss design, radiation tolerant design and novel packaging techniques are appropriate technologies for consideration.
- New and novel application of technologies for manufacturing, integration and test of micro/nano size spacecraft are sought. Limited production runs of up to several hundred spacecraft can be considered. Efficiencies can derive from increased reliability, flexibility in the end-to-end production process as well as cost, labor and schedule.
- Technologies that support passive and active thermal control suitable for micro and nano size spacecraft are sought. These functions include heat generation, storage, rejection, transport and the control of these functions. Efficient system level approaches for integrated small spacecraft that may see a wide range of thermal environments are desirable. These environments may range from low heliocentric orbits to two-hour shadows.
- Elements that support earth-to-space or space-to-space communications functions are sought. This includes receivers, transmitters, transceivers, transponders, antennas, RF amplifiers and switches. S and X are the target communications bands.

- Systems architectures and hardware that lead to greater spacecraft and constellation autonomy and therefore reduce operational expenses are desired. Technologies that derive added capability for a fixed bandwidth, efficient utilization of ground systems, status analysis and situation control or other enhancing performance for operations are sought.
- Structure and mechanism technologies and material applications that support the micro/nano class of spacecraft are desired. Exoskeleton structures, spin release mechanisms, and bi-stable deployment mechanisms are typical of the desired technology.
- Propulsion system elements that provide delta-V capability for spinning and/or three axis stable spacecraft are sought. This includes solid, cold-gas and liquid systems and their components such as igniters, thrust vector control mechanisms, tanks, valves, nozzles, and system control functions.

S1.05 Spacecraft and Space Environment Interaction
Lead Center: MSFC
Participating Center(s): GRC, GSFC, JPL

This subtopic is concerned with the effects of ionizing radiation, electromagnetic fields, plasma and thermosphere, and thermal and solar components of the environment on spacecraft systems, materials, as well as aeronautics and ground-based technologies. Innovative systems, components, and engineering tools are sought that increase reliability in the harsh environment of space, or that mitigate its effects. Materials sought include advanced thermal control coatings, multi-layer insulation materials, polymeric films, optical materials, seals, marker/astronaut visual aid coatings, and radiation shielding. Innovative engineering tools and models are sought that improve reliability and/or performance of avionic and ground-based systems.

New processing and application techniques are sought that reduce the cost or increase the performance reliability of current space-qualified materials and coatings. Low-cost, lightweight materials and protective coatings that mitigate environmental effects are also sought.

Specific areas for which proposals are sought include:

- Cost-effective methods for improving radiation tolerance of microelectronics and photonics including the reduction of single event upsets and other single particle-induced soft errors, and elimination of single event latchups and other single particle-induced destructive conditions.
- Cost-effective mitigation of radiation effects.
- Techniques for electrically grounding spacecraft to mitigate spacecraft charging.
- Techniques for controlling spacecraft potentials actively or passively.
- Other methods to mitigate harmful effects of space plasma and spacecraft charging.
- Preventing or mitigating the effects of space plasma electrical discharges on solar arrays and surfaces.
- Stable, electrically conductive but thermally advantageous coatings for spacecraft surfaces.
- Materials that electrically are partially insulating but that also “bleed off” buried charge.
- Flexible materials capable of withstanding ultraviolet and particulate radiation without embrittlement.
- Development of design guidelines for missions closer than 1 AU to the sun.
- Advanced materials for fasteners, including thread, hook-and-loop fasteners, structural adhesives with minimal outgassing characteristics, and EVA tethers.
- Cost-effective methods for ground-based simulation of the natural space environment.
- Development of novel methods of increasing aeronautic crew safety and system performance against the propogated effects of the natural space environment.
- Development of novel methods of increasing ground-based system performance and reliability from the propogated effects of the natural space environment such as soft error issues or power grid array.

S1.06 UV and EUV Optics and Detectors
Lead Center: GSFC
Participating Center(s): MSFC

Remote imaging, spectroscopy, and polarimetry at ultraviolet (UV) and extreme ultraviolet (EUV) wavelengths are important tools for studying the Sun-Earth connection from the Sun's atmosphere to the Earth's aurora. A far ultraviolet (FUV) range is sometimes interposed between UV and EUV, but the terminology is arbitrary: the pertinent full range of wavelength is approximately 20-300 nm.

The proposal should explain specifically how it intends to advance the state of the art in one or more of the following areas:

Imaging Mirrors
- Large aperture: 1-4 m
- Low mass: 5-20 kg m-2
- Accurate figure: ~0.01 wave rms or better at 632 nm. Figure accuracy must be maintained through launch and on orbit (including for mirrors subjected to direct or concentrated solar radiation, the effects of differential heating)
- Low microroughness: ~1 nm rms or better on scales below 1 mm

Optical Coatings and Transmission Filters
- Coatings (filters) with improved reflectivity (transmission) and selectivity (narrow bands, broad bands, or edges). Technologies include (but are not limited to) multilayer coatings, transmission gratings, and Fabry-Pérot étalons.

Diffraction Gratings
- High groove density (> 4000 mm-1) for high spectral resolving power in conjunction with achievable focal lengths and pixel sizes
- High efficiency and low scattter (microroughness)
- Variable line spacing
- Echelle gratings
- Active gratings (replicated onto deformable surfaces)

Detectors
- Large format (4K x 4K and larger)
- High quantum efficiency
- Small pixel size
- Large well depth
- Low read noise
- Fast readout
- Low power consumption (including readout)
- Intrinsic energy and/or polarization discrimination (3d or 4d detector)
- Active pixel sensors (back-illumination, UV sensitivity)

S2 Structure and Evolution of the Universe

The goal of the Space Science Enterprise's Structure and Evolution of the Universe (SEU) Theme is to seek the answer to three fundamental questions: (1) What is the Structure of the Universe and what is our Cosmic Destiny? (2) What are the cycles of matter and energy in the evolving Universe? (3) What are the ultimate limits of gravity and energy in the Universe? SEU’s strategy for understanding this interactive system is organized around four fundamental quests designed to pursue the following: (A) Identify dark matter and learn how it shapes galaxies and systems of galaxies, (B) Explore where and when chemicals elements where made, (C) Understand the cycles in which matter, energy and magnetic fields are exchanged between stars and the gas between stars, (D) Discover how gas flows in disks and how cosmic jets formed, (E) Identify the sources of gamma-ray bursts and high energy cosmic rays and F)Measure how strong gravity operates near black holes and how it affects the early universe. The technologies needed to achieve these goals fall into the following categories: (1) Detectors and sensors (2) Optical technologies (3) Long lived thermal control and cryogenic systems (4) Multiple coordinated observatories (5) Advanced detectors technologies (6) Ultra long duration terrestrial and extra-terrestrial balloons and aerobots technologies.

S2.01 Sensors and Detectors for Astrophysics
Lead Center: JPL
Participating Center(s): GSFC

Space science sensor and detector technology innovations are sought in the following areas:

Space VLBI
Very Long Baseline Interferometry (VLBI) systems with one element in space (called Space VLBI) need development of space-borne, low-power, ultra-low-noise amplifiers (less than 5x the quantum limit at 43 GHz and 86 GHz) to serve as primary receiving instruments. Also needed are light-weight, deployable (up to 50-meters diameter), space-borne radio telescopes with high efficiency at millimeter-wave observing bands (up to 86 GHz) to serve as primary observing instruments.

Far Infrared/Submillimeter
Future, space-based observatories in the 40 micron to 1 mm spectral regime will be cooled to cryogenic temperatures, greatly reducing background noise from the telescope. In order to take advantage of this potentially huge gain in sensitivity, improved detectors and detector arrays are required. The goal is to provide noise equivalent power less than 10-20 W Hz-1/2 over most of the spectral range in a 100x100 pixel detector array, with low-power dissipation array readout electronics. The ideal detector element would count individual photons and provide some energy discrimination. For detailed line mapping (e.g., C+ at 158 micron), heterodyne arrays operating in the same frequency range near the quantum limit are desirable.

X-ray
Improvements in material growth techniques for solid state hard X-ray detectors. Large format detectors for use with “lobster eye” X-ray optics. Could be arrays of CCDs, silicon strip detectors, or gas micro-strip or micro-gap detectors, optimized for low energy X-ray operation in relatively low-rate environments. Micro-well structures on amorphous thin film transistor arrays for two-dimensional pixel readout with fine pitch (few hundred microns) for large X-ray and gamma-ray area arrays (meters scale).

S2.02 Terrestrial and Extra-Terrestrial Balloons and Aerobots
Lead Center: GSFC
Participating Center(s): JPL, LaRC

Innovations in materials, structures, and systems concepts have enabled buoyant vehicles to play an expanding role in NASA's Space and Earth Science Enterprises. A new generation of large, stratospheric balloons based on advanced balloon envelope technologies will be able to deliver payloads of several thousand kilograms to above 99.9 percent of the Earth's absorbing atmosphere and maintain them there for months of continuous observation. Balloons will also carry scientific payloads on Mars, Venus, Titan, and the outer planets in order to investigate their atmospheres in situ and their surfaces from close proximity. Their envelopes will be subject to extreme environments and must support missions with a range of durations. Robotic balloons, known as aerobots, have a wide range of potential applications both on Earth and on other solar system bodies. NASA is seeking innovative and cost effective technologies in support of terrestrial and extra-terrestrial balloons and aerobots in the following areas:

Materials

- Membranes for terrestrial applications having strengths in excess of 7600 N/m and areal densities less than 40 g/m^2. Also desired are films, fibers, and innovative construction techniques that would lead to composite membranes achieving these strength and density goals. Additional material design considerations include resistance to UV degradation, operating temperatures between 180K and 300K, resistance to fracture, resistance to creep, low helium permeability, low and absorptivity to emmisivity ratio, high toughness, and good handling, folding, and seaming characteristics. Material must be producible to lay flat for a width of at least 1.53 meters.
- Membranes for extra terrestrial applications having yield strengths in excess of 150-200 MPa and areal densities less than 10-12 g/m^2. Also desired are films, fibers, and innovative construction techniques that would lead to composite membranes achieving these strength and density goals. For planetary applications, operating temperatures of the membranes are 70-90K (Titan), 140-300K (Mars) and 250-750k (Venus). Cold, brittleness point of the membranes should be below the operating temperature range.

Support systems
- Trajectory control techniques for maneuvering terrestrial and extra-terrestrial aerobots both horizontally and vertically
- Low weight power systems for terrestrial balloons that produce 2 kW or more continuously
- Power systems that enable long duration, polar night missions
- Innovative, low cost, low power, low weight, precision pointing systems that permit arcsecond or better accuracy

Design and Fabrication
- Efficient and cost-effective balloon envelope seaming, fabrication, and inspection techniques that lower costs and increase quality
- Innovative balloon design concepts that reduce material strength requirements, increase reliability, enhance performance, or improve mission flexibility

Deployment and inflation of planetary balloons
- Low weight systems for controlled deployment of balloons during atmospheric descent with mitigation of deployment shocks for Mars applications
- Low-weight high pressure tanks for gas storage
- Automatic inflation and launch from the planetary surface

S2.03 Multiple Coordinated Observatories
Lead Center: GSFC
Participating Center(s): None

A revolution is taking place in the way we conduct a range of space science missions. Specifically, the next decade will bring over 20 missions which involve formations of coordinated, observing platforms, or virtual platforms (VPs) in order to enable very long baseline imaging systems, high angular resolution interferometry, and complex communications networks to name a few. These distributed systems will operate under virtual infrastructures capable of responding to changing needs and conditions while evolving over time to introduce new capabilities. Representative mission scenarios include maintaining a specified satellite formation geometry at key points in the trajectory, maintaining the relative motion among co-orbiting spacecraft throughout the orbit, or maintaining relative positioning and attitude for targeting starts and other points distant in this or other solar system. Some of the more challenging scenarios involve the measurement of gravity waves and the imaging of black holes. These missions have relative measurement and/or control requirements on the order of nano- or even picometers, sometimes at tens, thousands, and even millions of kilometers apart. Frequently, these requirements go beyond the capability of current technology in the ability to sense and control position and orientation. Additionally, distributed spacecraft concepts of collective pointing and phasing of a number of observing systems relative to a target of interest or coordinated pointing (pointing the formation to collect related data from different selected angles) are critical to many of these mission scenarios. In addition to the dynamic behavior of each individual spacecraft, the collective behavior of all the spacecraft in the formation will determine the quality and the magnitude of the science return.

The requirements for coordinating these platforms have necessitated a major change in how we analyze, design, operate, and maintain space-based observatories. In particular, in many cases, several of the spacecraft bus components, which were at one time virtually decoupled from the payload or science sensor, are now fully integrated and fully coupled together operationally. This is the case for a wide range of interferometry missions where the interferometric measurements, which provide the primary science product, are the only measurements available at the precision required to maintain the spacecraft formation. This concept, fitting largely into a category of "real-scene wavefront sensing," is the primary technology focus for this call.

This subtopic calls for novel approaches to high precision relative and/or absolute sensing of multiple spacecraft position and orientation errors for the purpose of controlling the fleet as a collective and coordinated observatory. Specifically, we are looking for proposals which address as many of the following technologies and concepts:

- Real-scene wavefront sensing
- Numerical mappings from sensed wavefront to control error signals

- Nonlinear, robust estimation algorithms/filters for error determination
- System-level, multi-stage sensing concepts for high precision, wide dynamic range application
- Low-cost solutions to high precision formation error measurement
- Sensing concepts which integrate wavefront measurement with independent navigation/attitude determination/relative range measurements to provide full system sensing solutions
- Fault-tolerant estimation algorithms

We would like to see solutions that involve integrated algorithms, software, and/or hardware, resulting in ground or space-based demonstrations, focused on supporting a range of unique and challenging missions in the SEU program.

S2.04 Thermal Control and Management
Lead Center: GSFC
Participating Center(s): JPL, MSFC

Future spacecraft and instruments for NASA's Space Science Enterprise will require increasingly sophisticated thermal control technology to meet the demands of tight control with minimal mass and power resources. Cryogenic structures and other large-scale applications (down to a few Kelvin) are clearly an emerging trend. Stringent optical alignment and sensor needs are requiring ever tighter temperature control, and heat flux levels from lasers and other similar devices are increasing. Large, distributed structures such as mirrors will require creative techniques to integrate structural, mechanical alignment, and thermal control functions. Nano and micro spacecraft will also drive the need for new technologies, particularly since such small spacecraft will have low thermal capacitance. This situation, combined with the need for tighter temperature control, will present a challenging situation when such spacecraft/instruments undergo transients. The use of "off-the-shelf" commercial spacecraft buses for science instruments will also present challenges. In general, high performance, low cost, low weight, and high reliability are prime technology drivers. Specific areas for which innovative proposals are sought include:

- Advanced thermal control coatings such as variable emissive surfaces that permit adaptive intelligent control
- Cryogenic (3 K to 80 K) heat transport devices for sensor and /or optics cooling which incorporate a diode function
- Integrated structural, alignment, and thermal control concepts for very large structures
- Advanced analytical techniques for thermal modeling, focusing on techniques that can be easily integrated with emerging mechanical and optical analytical tools
- Advanced high conductivity materials, such as diamond films, which may be suitable for cryogenic applications

Many future space missions will have operational lifetimes of 5 to 15 years and will require similar lifetimes for cryogenic cooling systems. Both the lifetime and the reliability of the cryogenic systems are critical performance concerns. Mechanical coolers, thermoelectric coolers, radiative coolers, magnetic coolers, and combinations of these will be considered. Of interest are cryogenic coolers for cooling detectors, telescopes and instruments with long life, low vibration, low mass, low cost, and high efficiency. Specific areas of interest include:

- Highly efficient coolers in the range of 4-8 Kelvin as well as 50 milli-Kelvin and below
- Essentially vibration-free cooling systems such as reverse Brayton cycle cooler technologies
- Highly reliable, efficient, low cost Stirling and pulse tube cooler technologies
- Highly efficient magnetic cooling technologies, particularly at very low temperatures
- Hybrid cooling systems that make optimal use of radiative coolers
- MEMS and miniature solid-state cooler systems

S2.05 Optical Technologies
Lead Center: GSFC
Participating Center(s): JPL, LaRC, MSFC

The NASA Space Science Enterprise is studying future missions to explore the Structure and Evolution of the Universe, which will require very large space observatories. In order to understand the Structure and Evolution of the Universe, a variety of observatories are necessary to observe cosmic phenomena from radio waves to the highest energy cosmic rays. These observatories will peer farther and view objects more fainter than current Earth-based or space-based observatories and therefore will have increased resolution and light-gathering ability by greatly increasing the aperture size. It also will be necessary to operate some of these telescopes at cryogenic temperatures and at a substantial distance from the Earth. Apertures for normal incidence optics are required in the range of 20 - 40 m in diameter, while grazing incidence optics are required to support apertures up to 10 m in diameter. For some missions, these apertures will form a constellation of telescopes operating as interferometers. These interferometric observatories will have effective apertures in the 100 - 1000 m diameter range. The observatories required for many future SEU missions will also be operated at cryogenic temperatures (30 K) and at a substantial distance from the Earth. Therefore, low mass of critical components such as the primary mirror and support and/or deployment structure is extremely important. It is also essential to develop actuators, deformable mirrors and other components for operation in a cryogenic environment. In order to meet the stringent optical alignment and tolerances necessary for a high quality telescope and to provide a robust design, there are potential significant benefits possible from employing systems that can adaptively correct for image degrading sources from inside and outside the spacecraft. This subtopic also includes correction systems for large aperture space telescopes that require control across the entire wavefront, typically at low bandwidth. The following technologies are sought:

- Large, ultra-lightweight optical mirrors including membrane optics for very large aperture space telescopes and interferometers
- Large, ultra-lightweight grazing incidence optics for x-ray mirrors with angular resolutions less than 5 arcsec
- Ultra-precise, low mass deployable structures to reduce launch volume for large-aperture space telescopes and interferometers
- Segmented optical systems with high-precision controls; active and/or adaptive mirrors; shape control of deformable telescope mirrors; image stabilization systems
- Advanced, wavefront sensing and control systems including image based wavefront sensors
- Shape measurement and control of large aperture membrane optics
- Wavefront correction techniques and optics for large aperture membrane mirrors and refractors (curved lenses, fresnel lenses, diffractive lenses)
- Cryogenic optics, structures, and mechanisms for space telescopes and interferometers
- Nanometer and picometer metrology for space telescopes and interferometers
- High-precision pointing and attitude control systems for large space telescopes and interferometers
- Space-fabricated optics and techniques including fabrication from raw materials or blanks, coatings, assembly of components, metrology, and system testing
- High-performance materials and fabrication processes for ultra-lightweight, high performance optics
- Advanced analytical models, simulations, and evaluation techniques and new integrations of suites of existing software tools allowing a broader and more in-depth evaluation of design alternatives and identification of optimum system parameters including optical, thermal, and structural performance of large space telescopes and interferometers
- Advanced, low-cost, high quality large optics fabrication processes and test methods including active metrology feedback systems during fabrication, and artificial intelligence controlled systems
- Technologies for testing new mirror materials and shapes in relevant environments including cryogenic testing.
- New coatings and methods for applying them
- Long path length measurement techniques
- Innovative solutions to detect and correct errors in deployed optical systems
- Deployable optical benches to achieve reference baseline dimensions greater than those of the payload envelope
- High resolution (2 nm) long stroke (6mm) cryogenic actuators
- Wide field of view optics using square pore slumped micro-channel plates or equivalent
- Coded masks for 5 mm x 5 mm x 5 mm pixels of high-Z passive metal (Pb or W) and ~4 m^2 area
- Grazing incidence focusing mirrors with response up to 150 keV
- Develop fabrication techniques for ultra-thin-flat silicon (or like material) for grating substrates for x-ray energies < 0.5 keV
- Large area thin blocking filters with high efficiency at low energy x-ray energies (< 600 eV)

Novel optical materials, specialized optical fabrication techniques, and new optical metrology instruments and components for Earth- and space-based applications are needed as follows:

- Develop novel materials and fabrication techniques for producing ultra-lightweight mirrors, high-performance diamond turned optics, and ultra-smooth (2-3 angstrom rms) replicated optics that are both rigid and light-weight. Lightweight silicon carbide optics and structures are also desired.
- Develop optics for focusing EUV and x-ray radiation where reductions in fabrication time and cost are sought. Developments are also needed in the areas of surface roughness and figure characterization of EUV and curved x-ray optics, especially Wolter systems.
- Develop novel materials and fabrication techniques for producing cryogenic optics. Testing techniques, including both full- and sub-aperture testing, for cryogenic optics are needed. Also desired are techniques for testing the durability of and stress in coatings used in harsh environments, particularly cryogenic optics.
- Develop novel techniques for producing and measuring coatings and polarization control elements. Optical coatings for use in the EUV, UV, visible, IR and far IR for filters, beamsplitters, polarizers, and reflectors will be considered. Broadband polarizing- and non-polarizing cube-type beamsplitters are also needed.
- Perform development related to fabrication of x-ray, gamma-ray, and neutron collimators that have the precision necessary to achieve arcsecond or sub-arcsecond imaging in solar physics and astrophysics when used in stationary multi-grid arrays or as rotating modulation.
- Develop portable and miniaturized state-of-the-art optical characterization instrumentation, and rapid, large-area surface-roughness characterization techniques are needed. Also, develop calibrated processes for determination of surface roughness using replicas made from the actual surface. Traceable surface roughness standards suitable for calibrating profilometers over sub-micron to millimeter wavelength ranges are needed.
- Develop instruments capable of rapidly determining the approximate surface roughness of an optical surface, allowing modification of process parameters to improve finish without the need to remove the optic from the polishing machine. Techniques for testing the figure of large, convex aspheric surfaces to fractional wave tolerances in the visible are needed.
- Develop efficient, analytical, optical modeling and analysis programs capable of determining the ground-based and space-based performance of complex aberrated optical telescopes and instrument systems will be considered. Also, simple, well documented, flexible programs, which generate commands to operate a numerically controlled polishing machine given the tool wear profile and surface error map are desired.
- Develop very low scattered light optical material thin film mirror coatings or mirrors for broad-band white light applications to planet detection space telescopes.
- Develop a novel material for producing doubly curved, ultra-thin, unsupported shell, optical quality, telescope mirrors which are capable of being rolled for storage and transport. These mirrors will exceed one meter in diameter, have an areal density of < 1.5 kg/m2, and have sufficient "memory" to enable it to return to its original configuration when unfurled. Fine adjustment will be achieved using actuator material embedded within the shell mirror or with a two-stage optics system or both. The reflective surface would not be damaged when the mirror is rolled. This material must tolerate the space environment without dimensional changes, stiffness changes, or loss of mechanical integrity.

S2.06 Advanced Photon Detectors
Lead Center: GSFC
Participating Center(s): JPL

The technical requirements to support the Structure and Evolution of the Universe (SEU) science theme missions are extremely diverse, which is a consequence of the wide-ranging nature of the investigations. Technology developments are sought in the system context from energy detection through data reduction and scientific visualization needed to implement SEU missions.

The next generation of astrophysics observatories for the infrared (IR), ultra-violet (UV), x-ray, and gamma-ray bands require order-of-magnitude performance advances in detectors, detector arrays, readout electronics and other supporting and enabling technologies. Although the relative value of the improvements may differ among the four energy regions, many of the parameters where improvements are needed are present in all four bands. In particular, all bands need improvements in spatial and spectral resolutions, in the ability to cover large areas, and in the ability to support the readout of the thousands/millions of resultant spatial resolution elements. The SEU program seeks innovative technologies to enhance the scope, efficiency and resolution of instrument systems at all energies/wavelengths.

- The next generation of gravitational missions will require greatly improved inertial sensors. Such an inertial sensor must provide a carefully fabricated test mass that has interactions with external forces (i.e., low magnetic susceptibility, high degree of symmetry, low variation in electrostatic surface potential, etc.) below 10^{-16} of the Earth's gravity, over time scales from several seconds to several hours. The inertial sensor must also provide a housing for containing the proof mass in a suitable environment (i.e., high vacuum, low magnetic and electrostatic potentials, etc.).
- Advanced CCD detectors, including improvements in quantum efficiency and read noise, to increase the limiting sensitivity in long exposures and improved radiation tolerance. Electron-bombarded CCD detectors, including improvements in efficiency, resolution, and global and local count rate capability. In the x-ray, we seek to extend the response to lower energies in some CCDs, and to higher, perhaps up to 50 keV, in others.
- Significant improvements in wide band gap (such as GaN and AlGaN) materials, individual detectors, and arrays for UV applications.
- Improved microchannel plate detectors, including improvements to the plates themselves (smaller pores, greater lifetimes, alternative fabrication technologies, e.g., silicon), as well as improvements to the associated electronic readout systems (spatial resolution, signal-to-noise capability, dynamic range), and in sealed tube fabrication yield.
- Imaging from low Earth orbit of air fluorescence UV light generated by giant airshowers by ultra-high energy ($E > 10^{19}$ eV) cosmic rays require the development of high sensitivity and efficiency detection of 300 - 400 nm UV photons to measure signals at the few photon (single photo-electron) level. A secondary goal minimizes the sensitivity to photons with a wavelength greater than 400 nm. High electronic gain ($\sim 10^6$), low noise, fast time response (< 10 ns), minimal dead time (< 5 percent dead time at 10 ns response time), high segmentation with low dead area (< 20 percent nominal, < 5 percent goal), and the ability to tailor pixel size to match that dictated by the imaging optics. Optical designs under consideration dictate a pixel size ranging from approximately 2 x 2 mm^2 to 10 x 10 mm^2. Focal plane mass must be minimized (2 g/cm^2 goal). Individual pixel readout. The entire focal plane detector can be formed from smaller, individual sub-arrays.
- For advanced x-ray calorimetry improvements in several areas are needed, including:
  - Superconducting electronics for cryogenic x-ray detectors such as SQUID-based amplifiers and their multiplexers for low impedance cryogenic sensors and super-conducting single electron transistors and their multiplexers for high impedance cryogenic sensors;
  - Micromachining techniques that enhance the fabrication, energy resolution, or count rate capability of closely-packed arrays of x-ray calorimeters operating in the energy range from 0.1 keV to 10 keV;
  - Surface micromachining techniques for improving integration of x-ray calorimeters with read-out electronics in large scale arrays.
- Improvements in readout electronics, including low power ASICs and the associated high density interconnects and component arrays to interface them to detector arrays.
- Superconducting tunnel junction devices and transition edge sensors for the UV and x-ray regions. For the UV, these offer a promising path to having "three dimensional" arrays (spatial plus energy). Improvements in energy resolution, pixel count, count rate capability, and long wavelength rejection are of particular interest. For the far-IR future background-limited SEU telescopes will need detectors with NEP < 10^{-20} Watts per root Hz packaged in 100x100 pixel arrays with low-power readout devices, and the ideal detectors would be energy-resolving. We seek techniques for fabrication of close packed arrays, with any requisite thermal isolation, and sensitive (SQUID or single electron transistor), fast, readout schemes and/or multiplexers.
- Arrays of CZT detectors of thickness 5 to 10 mm to cover the 10 - 500 keV range, and hybrid detector systems with a Si CCD over a CZT pixelated detector operating in the 2 - 150 keV range.

S3 Astronomical Search for Origins

NASA's Origin's Program seeks the answers to two broad questions related to life on Earth as we know it. How did we get here and are we alone? The answers lie in an understanding of how galaxies, stars, and planetary systems were formed in the early universe. We must determine whether planetary systems and Earth-like planets are typical companions of average stars and if life beyond Earth is a rare, possibly nonexistent, occurrence or if it is robust and has spread throughout the galaxy. Origin's primary mission goals are to study the early universe, find planets around other stars, and search for life beyond Earth. The technologies and discoveries needed to achieve these goals fall into the categories of very large space observatory systems, precision spacecraft constellations, advanced astronomical instrumentation, and new techniques for laboratory astrobiology.

S3.01 Ultralight Adaptive Large Telescope Systems
Lead Center: MSFC
Participating Center(s): GSFC, JPL, LaRC

The long-range goal of the Astronomical Search for Origins and Planetary Systems (ASO) theme in the Space Science Enterprise is to detect, characterize, and ultimately image extra-solar planets in orbit around nearby stars. Results from these efforts may provide clues as to the existence of life on these planets and the nature of life within our own solar system. The level of image resolution needed to accomplish these observations requires the development of telescopes with light gathering apertures that are many times the size of NASA's 8-meter Next Generation Space Telescope (NGST). Such large aperture requirements have recently stimulated the development of new and unconventional telescope design concepts, ranging from single light collection stations employing a myriad of distributed reflective mirrors to constellations of large telescopes flying in formation and operating as interferometers.

In addition to a large aggregate aperture requirement, these new observatories must maintain a low areal density (including the optics, reaction structure, actuators, and wiring). 100 kg/m2 is typical for conventional telescopes, and NGST is striving to achieve between 10 and 15 kg/m2. However, for ASO missions and other future telescope programs, areal densities of “ kg/m2 or less are required to enable affordable and launchable system architectures. Other system design considerations include the ability to deploy components from a stowed launch configuration to a final on-orbit configuration without degrading the system's optical quality, the need for precise structural and system control mechanisms used to maintain diffraction-limited imaging capabilities, and the ability to successfully endure and perform within the harsh space environment.

Specifically, this subtopic is soliciting concepts and enabling technologies for large space-based telescope systems designed to accomplish either near-term objectives (i.e., ~10m apertures and 1-10kg/m^2 areal densities) and/or far-term objectives (i.e., 20-40m apertures and < 1kg/m^2 areal densities). Specific areas of interest include:

- Novel concepts for space telescope system design and implementation
- Active/adaptive wavefront sensing and control at ambient and cryogenic temperatures
- Large, lightweight, cryogenic, optical materials
- Large, transmissive optics and optical materials
- Large, reflective optics and optical materials
- Low cost, in situ metrology techniques for space-deployed optics
- Low areal density precision structures
- Pliable structures with shape memory
- Low weight, low cost actuators for optical surfaces
- Deformable, controllable optics
- Membrane mirrors
- Non-contacting, shape control actuation for membrane mirrors
- Integral membrane mirror and shape control actuation subsystem
- Membrane mirror packaging and deployment
- Large, aperture telescope structures, materials, and deployment

S3.02 Precision Constellations for Interferometry
Lead Center: JPL
Participating Center(s): None

This subtopic includes hardware and software technologies necessary to establish, maintain and operate hyper-precision spacecraft constellations at a level that enables separated spacecraft optical interferometry. Also included are technologies for analysis, modeling and visualization of such constellations.

In a constellation for large effective telescope apertures, multiple, collaborative spacecraft in a precision formation collectively form a variable-baseline interferometer. These formations require the capability for autonomous precision alignment and synchronized maneuvers, reconfigurations, and collision avoidance. It is important that, in order to enable precision spacecraft formation keeping from coarse requirements (relative position control of any two spacecraft to less than one cm, and relative bearing of 1 arcmin over target range of separations from a few meters to tens of kilometers) to fine requirements (micron relative position control and relative bearing control of 0.1 arcsec), the interferometer payload would still need to provide at least 1 to 3 orders of magnitudes improvement on top of the S/C control requirements. The spacecraft also require onboard capability for optimal path planning, and time optimal maneuver design and execution.

Innovations that address the above precision requirements are solicited for distributed constellation systems in the following areas:

- Integrated optical/formation/control simulation tools
- Distributed, multi-timing, high fidelity simulations
- Formation modeling techniques
- Precision guidance, control architectures and design methodologies
- Centralized/decentralized formation estimation
- Distributed sensor fusion
- RF/optical precision metrology systems
- Formation sensors
- Precision micro-thrusters/actuators
- Autonomous re-configurable formation techniques
- Optimal, synchronized, maneuver design methodologies
- Collision avoidance mechanisms
- Formation management and station keeping
- Six degrees of freedom precision formation testbeds

S3.03 Astronomical Instrumentation
Lead Center: JPL
Participating Center(s): ARC

Much of the scientific instrumentation used in future NASA observatories for the Origins Program theme will be similar in character to instruments used for present day space astrophysical observations. However, the performance and observing efficiency of these instruments must be greatly enhanced. The instrument components are expected to offer much higher optical throughput, larger fields of view, and better detector performance. The wavelengths of primary interest extend from the near-infrared to past 100 microns. Measurement techniques include imaging, photometry, spectroscopy, coronography, and polarimetry. Of particular interest are technologies supporting the following:

Advanced Detectors
These efforts should propose breakthrough capabilities in spectral coverage, large array size with uniform high quantum efficiency, ultra-low dark current, elevated operating temperatures, spectroscopic capabilities, or their ability to operate effectively and reproducibly over long periods (ex. 5-10 years of space observations at low power, extreme temperatures, etc.).

High Performance Filters
There is a critical need for filters with good in-band transmission and very low out-of-band transmission at all wavelengths of interest but particularly at wavelengths > 5 microns. Desirable passbands range from 50 percent to less than 1 percent with in-band transmissions > 70 percent.

Other Optical and Opto-mechanical Instrument Components
Given the call for multiple capability instruments, there is a growing need for breakthrough concepts in instrument optics which minimize the volume requirements while adding capabilities (spectral, or otherwise) to the instrument. These elements may include gratings, prisms, dichroics, or other novel components.

Mechanical Coolers
The best detectors for wavelengths > 5 microns usually need to be cooled to < 10 K. There are a number of proposed Origins missions which have cooling requirements from 50 mK to 20 K; highly stable (both mechanical and temperature stability), long life coolers are needed for these. Efforts may address the component level such as materials for magnetic refrigerants or novel heat switches, or they may address entire systems such as pulse tube, J-T, sorption, or sub-kelvin coolers.

S3.04 Astrobiology
Lead Center: ARC
Participating Center(s): None

Astrobiology includes the study of the origin, evolution and distribution of life in the universe. New technologies are required to enable the search for extant or extinct life elsewhere in the solar system, to obtain an organic history of planetary bodies, to discover and explore water sources elsewhere in the solar system and to distinguish microorganisms and biologically important molecular structures within complex chemical mixtures. For example, gaseous biomarkers, produced by microbial communities, are among our targets in current search strategies for life in the atmospheres of extrasolar planets. Both gaseous and mineral biomarkers produced by these communities are profoundly affected by internal biogeochemical cycling. The small spatial scales at which these biogeochemical processes operate necessitate measurements made using microsensors. Microbial ecology research at NASA could benefit enormously from collaboration of sensor technologists and microbial ecologists. The search for life on other planetary bodies will also require systems capable of moving and deploying instruments across and through varied terrain to access biologically important environments.

A second element of Astrobiology is the understanding of the evolutionary development of biological processes leading from single cell organisms to multi-cell specimens and to complex ecological systems over multiple generations. Understanding the effects of gravity on the evolution of living systems is a fundamental question of substantial, inherent scientific value in our quest to understand life. In addition, radiation of varying levels is assumed to have varying effects on the development and evolution of life. Knowledge of the effects of radiation and gravity on lower organisms, plants, humans and other animals (as well as elucidation of the basic mechanisms by which these effects occur) will be of direct benefit to the quality of life on Earth. These benefits will occur through applications in medicine, agriculture, industrial biotechnology, environmental management and other activities dependent on understanding biological processes over multiple generations.

A third component of Astrobiology includes the study of evolution on ecological processes. Astrobiology intersects with NASA Earth science studies through the highly accelerated rate of change in the biosphere being brought about by human actions. One particular area of study with direct links to Earth science is microbe-environment interactions. These interactions can be seen in carbon cycles and nitrogen cycles. Some examples of rapid changes that affect these microbial processes are increases in UV, increases in average and seasonal temperatures, and changes in the length of the growing season, all which are key issues in both Earth Science and Astrobiology. Additional areas include Controlled Environment Sustainability Research (CESR), growth chambers and monitoring capabilities. This research requires unique instrumentation and information science technologies that are not covered in the Earth science program.

NASA seeks innovations in the following technology areas:

Mobility/Sampling/Subsurface Water Detection Systems
- Innovative techniques that meet these needs are required, e.g., for Mars exploration, technologies that would enable the aseptic acquisition of deep subsurface samples, the detection of aquifers, or the enhancement at the performance of long distance ground roving, tunneling, or flight vehicles are required. For Europa exploration, technologies which enable the penetration of deep ice are required. Desirable features for both Mars and Europa exploration include the ability to carry an array of instruments and imaging systems, to provide aseptic operation mode, and to maintain a pristine research environment.
- Low cost lightweight systems to assist in the selection and acquisition of the most scientifically interesting samples are also of significant interest.

Analytical Tools

- High sensitivity (femtomole or better), high resolution methods applicable to all biologically relevant classes of compounds for separation of complex mixtures into individual components.
- Advanced in situ and laboratory based, microbial sensing/monitoring system capable of providing quantitative spatial and temporal visualization of material and functions in selected specimens. Advanced miniaturized biological in situ sample acquisition and handling systems optimized for extreme environment applications.
- High sensitivity (femtomole or better) characterization of molecular structure, chirality, and isotopic composition of biogenic elements (H, C, N, O, S) embodies individual compounds and structures.
- High spatial resolution (5 angstrom level) electron microscopy techniques to establish details of external morphology, internal structure, elemental composition and mineralogical composition of potential biogenic structures.
- Innovative software to support studies of the origin and evolution of life. The areas of special interest are (1) biomolecular and cellular simulations; (2) evolutionary and phylogenetic algorithms and interfaces; (3) DNA computation; and (4) image reconstruction and enhancement for remote sensing.
- In order to address the imperative to understand gaseous biomarker production, we desire technologies capable of measuring a range of volatile compounds at small spatial scales, possibly through the coupling of gas diffusion sensors to portable mass spectrometers. Improved sensor designs for a wide range of analytes, including oxygen, pH, sulfide, carbon dioxide, hydrogen, and small molecular weight organic acids both on and near surfaces that could serve as habitats for microbes.
- Nondestructive structural characterization of micro-areas of microsamples of rocks and minerals by diffraction (1-100 micron scale). Tools to Support Gravity and Radiation Studies of Biological Systems over Multiple Generations These technologies must be miniaturized to minimize weight, volume and power requirements and must operate autonomously for extended periods of time to accommodate monitoring multiple generations of organisms. Thus, instrumentation must be self-calibrating, require no or minimal consumables and be remotely controlled.
- Biotechnology - determining mutation rates and genetic stability in a variety of organisms as well as accurately determining protein regulation changes in microgravity and radiation environments.
- Automated chemical analytical instrumentation for determining gross metabolic characteristics of individual organisms and ecologies as well as chemical composition of environments.
- Spectral/imaging technology with high resolution and low power requirements.
- Habitat support - technologies for supporting miniature ecosystems isolated from their support environments, data collection and transmission technologies in concert with the automated chemical instrumentation described above. Candidate technologies include sensor and telemetry systems as well as variable-spectrum, low power light sources for simulating conditions on the early Earth.

Algorithms for processing and analyzing recovered data. Instrumentation and information technologies to support the study of evolution of ecological processes and CESR are:

- Miniature to microscopic, high resolution, field worthy, smart sensors or instrumentation for the accurate and unattended monitoring of environmental parameters that include, but are not limited to, solar radiation (190-800 nm at < 1nm resolution), ions and gases of the various oxidation states of carbon and nitrogen (at the nanomolar level for ions in solution and at the femtomolar or better level for gases), in a variety of habitats (e.g., marine, freshwater, acid/alkaline hot springs, Antarctic climates or boreholes into the Earth).
- High resolution, high sensitivity (femtomole or better) methods for the isolation and characterization of nucleic acids (DNA/RNA) from a variety of organic and inorganic matrices.
- Mathematical models capable of predicting the combined effects of elevated pCO2 (change in CO2 over the eons) and solar UV radiation on carbon sequestration and N2O emissions from experimental data obtained from field and laboratory studies of C-cycling rates, N-cycling rates, as well as diurnal and seasonal changes in solar UV.
- Microscopic techniques and technologies to study soil cores, microbial communities, pollen samples, etc. in a laboratory environment for the detailed spectroscopic analysis relevant to evolution as a function of climate changes.
- Robotic system designed to provided access to terrestrial and extraterrestrial environments such as deep ocean, hydrothermal vents.

S3.05 High Contrast Astrophysical Imaging
Lead Center: JPL
Participating Center(s): None

This subtopic addresses the unique problem of imaging faint astrophysical objects that are located within the obscuring glare of much brighter sources. Some examples include planetary systems beyond our own and the detailed, inner structure of galaxies with very bright nuclei. Contrast ratios of one million to one billion over an angular spatial scale of less than one arcsecond are typical of these objects.

The innovative research focuses on advances in coronagraphic and star light cancellation instruments that operate at visible and infrared wavelengths. Typically, these instruments would be intended for operation in space as part of a future observatory mission. Some examples of areas of interest include:

- Ultra-low scatter optics and coatings
- Advanced aperture apodization techniques
- High precision, wavefront, error sensing techniques
- Small stroke, high precision deformable mirrors and controllers
- Advanced starlight coronagraphic instrument concepts
- Interferometric starlight cancellation techniques

For infrared applications, operating at cryogenic temperatures is a typical requirement.

S4 Exploration of the Solar System

NASA's program for Exploration of the Solar System seeks to answer fundamental questions about the Solar System and life: How do planets form? Why are planets different from one another? Where did the makings of life come from? Did life arise elsewhere in the Solar System? What is the future habitability of Earth and other planets? The search for answers to these questions requires that we augment the current remote sensing approach to solar system exploration with a robust program that includes in situ measurements at key places in the Solar System and the return of materials from them for later study on the Earth. We envision a variety of missions to achieve this including a comet nucleus sample return, a Europa lander, a rover or balloon-borne experiment on Saturn's moon Titan, and a possible Pluto Express to name a few. Numerous, new technologies will be required to enable such ambitious missions.

S4.01 Science Instruments for Conducting Solar System Exploration
Lead Center: JPL
Participating Center(s): ARC

Being able to achieve the Solar System exploration goals requires innovative miniaturized science instruments and instrument components that offer significant improvement over the state of the art in terms of size, mass, power, cost, performance, and robustness. This subtopic seeks to support the development of advanced instrument technology that has potential for scientific investigation on future planetary missions. New measurement concepts, advances in existing instrument concepts, advances in critical components such as detectors, sampling handling techniques and technologies that enable integrated instrument architectures are all of interest. Proposers are encouraged to relate their proposed technology development to future planetary science goals as much as possible.

While both remote and in situ sensing instruments are of interest, NASA’s space science missions will increasingly rely upon in situ characterization of the atmosphere, surface and subsurface regions of planets, satellites, and small bodies. These instruments may be deployed on surface landers and rovers, subsurface penetrators, cryobots, and airborne platforms. These instruments must be capable of withstanding operation in space and planetary environmental extremes, which include temperature, pressure, radiation, and impact stresses. A reasonable target for an in situ science instrument concept is 1-kilogram mass, 1-liter volume, and 1 watt-hour of energy although for mission critical capabilities, additional resources might be available.

A wide range of in situ instruments is of interest--geological, chemical, biological, physical, and environmental. Particular emphasis is needed for astrobiology related measurements seeking to understand the origin and evolution of life and pre-biotic processes. New in situ analysis techniques are desired to identify and quantify biogenically important elements (C, H, N, O, P, and S) and their compounds (e.g., CH4, NOx, H2O) within extraterrestrial atmospheres, soils, ices, sedimentary rocks, and minerals.

The following future mission needs will receive emphasis during proposal selection.

Mars Surveryor Missions. Missions to Mars will include both orbiters and landers with launches occuring approximately every 26 months. The high-level science drivers for Mars include determining if life ever arose on Mars, characterizing the ancient and present climate as well as climate processes, determining the evolution of the Martian surface and interior, and characterizating of the environment in preparation for human exploration.

Outer Solar System Missions. Future, outer planet, mission opportunities might include a Europa lander, a Titan lander, a Pluto Express, and/or a comet nucleus sample return. Instruments for Europa and Titan are particularly challenging because of the extreme environmental constraints. Europa measurement needs include characterization of the near-surface composition, determination of the compositional, geophysical, and geological context for the surface site, and a search for indications of Europan biology. Titan drivers include a determination of the distribution and composition of organics, and atmospheric dynamics.

Discovery Program Missions. Discovery program missions represent a series of competed focused missions to a variety of solar system objects. These objects may include orbiters, landers, flybys, balloons, and airplanes to study a wide variety of science goals involving geology, geochemistry, geophysics, atmospheres and climates, and particles and fields. Instrumentation and instrument concepts that address this broad range of needs will be considered.

Example Measurement Needs
Meeting the needs for the Solar System exploration goals requires a significant arsenal of advanced scientific instrumentation. Examples of instruments that might meet some of the above goals include, but are not limited to, the following:

- Chemical sensing instrumentation for the surface and subsurface chemical, mineralogy, and isotopic analysis of soils, rocks, and ices. Examples include Raman spectrometers, laser-induced breakdown spectrometers, water/ice detectors, age-dating systems, electrochemical systems, thin film sensors, liquid and gas chromatography systems, gas chromatograph-mass spectrometers and other mass analyzing systems.
- Instrumentation focused on exobiological assessments for the identification and characterization of biomarkers of extinct or extant life or prebiotic molecules. Examples include ultraviolet-Raman, infrared reflectance and transmittance, fluorescence microscopy, total organic carbon analyzers, microcalorimetry concepts, NMR spectroscopy, chromatography systems, CHONS isotope analysis, biosensor concepts, ion mobility spectrometers or other molecular identification instrumentation capable of operating alone or as part of a gas chromatograph system.
- Sensing instrumentation that integrates such functions as separation, reagent addition, and detection, especially using emerging "lab-on-a-chip" technologies.
- Suboptical microscopy instrumentation to characterize morphology, elemental and mineralogical composition, such as electron microscopy techniques and atomic force microscopy.
- Instrumentation for the chemical and isotopic analysis of planetary atmospheres.
- Physical and environmental sensing systems, such as seismic and meteorological sensors, humidity sensors, wind and particle size distribution sensors.
- Particles and fields measurements, such as magnetometers, and electric field monitors.
- Enabling in situ instrument component and support technologies, such as 2-10 micron laser sources, miniaturized pumps, sample inlet systems, valves, and fluidic technologies for sample preparation.
- Advanced detectors and focal plane arrays in the regimes of radar/sub-mm through IR/Vis/UV.

S4.02 Planetary Mobility and Robotics, Sub-Surface Access, and Autonomous Control Technologies
Lead Center: JPL
Participating Center(s): ARC

During the future exploration of planetary and lunar surfaces and the surface of small solar system bodies (such as comets and asteroids), new tools in the areas of surface robotic systems, sub-surface systems, aerial systems, and autonomous software need to be developed. These technologies are required for advanced scientific exploration of planetary surfaces by providing access to challenging surface sites, collection of sub-surface samples, investigation of a site through an aerial survey, and the software required for long-duration survival on the planet surface. In particular, this subtopic seeks to solicit research contributions that are in the following areas:

- Airborne systems includ autonomous fixed-wing aircraft, airships or blimps for long-duration scientific investigations, and aerobots and balloons for atmospheric and surface exploration.
- Surface systems includ science rovers for detailed in situ investigation, advanced surface mobility systems for access to high-risk terrain, manipulation and sample-handling systems for precision placement of instruments and sampling systems, and multiple, cooperating robotic systems for the development of a sustained robotic presence through robotic colonies and sensor webs.
- Sub-surface systems includ shallow sampling systems for robust collection of rock and soil samples from less than 1 meter in depth, deep drilling systems for exploration of sub-surface strata including the search for possible sub-surface water aquifers, low-cost, low-mass penetrator systems that are capable of conducting limited scientific discovery over a wide terrain area, sub-surface mobility systems that allow for the autonomous exploration of sub-surface material including soil, rock, and ice, and autonomous underwater robotic systems for exploration of possible sub-surface oceans on the moons of Jupiter.
- Autonomous software technologies includ autonomous navigation techniques, algorithms for multiple cooperating systems, behavior-based control systems, advanced path planning techniques, software for intelligent systems, robotic reconfiguration strategies, and autonomous scientific data collection.

S4.03 Detection and Reduction of Biological Contamination on Flight Hardware
Lead Center: JPL
Participating Center(s): ARC

As space flight missions venture into planetary atmospheres and onto surfaces, NASA is committed to the implementation of its planetary protection policy and regulations. There is a need to support projects in all mission phases from design to close-out. One of the great challenges is to develop or find the technologies that will make compliance with planetary protection policy routine and affordable. Planetary protection is directed to (1) the control of terrestrial microbial contamination associated with robotic space vehicles intended to land, orbit, flyby, or otherwise be in the vicinity of extraterrestrial solar system bodies, and (2) the control of contamination of the Earth by extraterrestrial solar system material collected and returned by such missions. The implementation of these requirements will ensure that biological safeguards to maintain extraterrestrial bodies as biological preserves for scientific investigations are being followed in NASA's space program.

To fulfill its commitment, NASA seeks technologies that will support its needs in the area of cleaning, cleaning validation, maintenance of biologically clean work areas, encapsulation and containerization, and archival preservation of organic and inorganic samples. Examples of such technologies include but are not limited to:

- Low temperature, non-corrosive, sterilization techniques (room temperature and below).
- Non-abrasive, cleaning techniques for narrow aperture, occluded areas.
- Ultra clean assembly processes for non-assembly line (unique and/or limited production) hardware.
- Direct and rapid in situ monitoring of particles and biological contamination on surfaces with various shape, finish, electrical conductivity, etc.
- Rapid cleaning validation methods with high sensitivity for the major classes of biological molecules: proteins, amino acid, DNA/RNA, lipids, polysaccharides.
- Containerization and encapsulation of samples to be returned to Earth, including innovative mechanisms for isolation, sealing, and leak detection.

S4.04 Lightweight Materials for Planetary Aerocapture, and Spacecraft Structures and Deployables
Lead Center: JPL
Participating Center(s): LaRC

The desire to launch deep space mission payloads on lower cost, smaller launch vehicles has increased as projects have become more constrained due to budget pressures. In light of these factors, new concepts of using thin film structures or space systems to accomplish mission critical functions such as mobility (balloons), aerocapture (ballutes), and deployable multifunctional structures (radiators, struts, antenna, etc.) are gaining importance. Low mass, low volume, space asset functionality is critical to enabling new missions to withstand the harsh environments (For example, temperature and atmospheric conditions) at Venus and Titan if we wish to dramatically reduce the cost of in situ science. We wish to identify, evaluate, and develop thin film materials, systems and associated technologies that will be compatible with ballute, balloon and the low-mass multifunctional-structure requirements listed below. A systems engineering perspective is encouraged. Proposals should address how materials/ configurations are compatible with expected preflight configurations, subsequent in-flight configurations, and attendant environments. Materials and processes and their associated mission use constraints and must have the potential to meet all important requirements, or they will not be considered.
Technology innovations sought include these areas:

- Ballute materials for aerocapture missions contain high temperature capability (> 400 C), high emissivity e > 0.8, low mass-areal density < 10 gm/m2, thin films with appropriate stability and dynamics response. The ability to withstand aerodynamic stresses/temperatures during deployment and aerocapture sequences.
- Balloon and aerobot materials and associated seaming technology with capability to withstand acidic (sulfuric acid) atmosphere and high temperatures (withstand up to 500 C - Venus or in the case of Titan down to -170 C) at areal densities of < 10gm/m2. Low packing density is needed for the launch and cruise phase of missions to Venus or Titan. Issues to address are mass, material strength (thin films/composites, metallization, rip stop properties), space environment durability and lifetime; retention of properties after tight packing; and manufacturing issues including edge capture, joint concepts, and prelaunch repair.
- Low mass multifunctional structures or membranes integrated with electronics, power sources, thermal control or communication capabilities with areal densities under 0.1 kg/m2 such that they would be applicable to large area ultra-lightweight deployable or inflatable structures. Specific areas of interest are thermal technologies for thin films and membranes; development of active or passive thermal control systems and models for the electronics integrated with membrane structures; development of substrate thinning and bonding processes; development of materials with controllable surface properties that, when combined with integrated control electronics, could adapt to changing environments or mission needs; space rigidizable thin films; and shape memory thin films/low density polymeric materials for deployable structures.

S4.05 Advanced Miniature and Micro Avionics and Electronics for Deep Space Systems
Lead Center: JPL
Participating Center(s): None

The strategic plan within the Space Science Enterprise at NASA requires intense exploration of a wide variety of bodies in the Solar System within a modest budget. To achieve this will require revolutionary advances over the capabilities of traditional spacecraft systems and a broadening of the tool set through the introduction of new kinds of space exploration systems. These systems will include, but are not limited to, orbiters, landers, atmospheric probes, rovers, penetrators, aerobots (balloons), planetary aircraft, subsurface vehicles (ice/soil), and submarines. Also of interest is the delivery of distributed sensor systems consisting of networks of tiny (< 1 kg), individual elements which combine sensors, control, and communications in highly integrated packages and which are scattered over planetary surfaces, atmospheres, oceans, or subsurfaces.

New technology is needed in all spacecraft areas for mass, power, and volume reductions, and for application to harsh environments such as extreme temperature, radiation, and mechanical shock. Advances in microelectronics, avionics architecture, packaging and thermal control are encouraged. Applicable technology areas include but are not limited to:

- Avionics, including highly integrated, ultra low power and extreme long life components
- Avionics components able to operate in extreme environments: low temperature, high temperature, high radiation
- Thermal management for electronics, including active and passive techniques
- Three-dimensional VLSI, chip stacking, multi-chip-module stacking and other advanced packaging techniques
- Low power, COTS-based radiation tolerant and advanced power management technique
- Radiation hard, high density, non-volatile mass memory
- Fault tolerance and onboard maintenance design and analysis techniques for severely constrained environments and extreme long life missions
- Concepts and designs for test and validation of design integrity and performance of IP based ASICs, mixed signal ASICs and MEMS
- High resolution, high sampling rate, low power and radiation-hardened, analog-digital converters, and digital signal processing hardware components with algorithm design environments for rapid design and prototyping

S4.06 Telecommunications Tech. for High Rate Transmission over Large Distances and Local Planetary Networks
Lead Center: JPL
Participating Center(s): GRC, GSFC

This subtopic discusses innovations for both Optical and RF communication technologies.

RF Communications
- Ultra-small, low-cost, low-power, innovative, deep-space transponders and components, including integrated circuits such as microwave monolithic integrated circuits (MMICs) and Bi-CMOS circuits. Signal processing circuits for receivers that provide carrier tracking, command and ranging capabilities. Low-voltage, multi-function MMIC designs to provide low-noise down-conversion, automatic gain-control, up-conversion, and transceiver functions at (Ka-band (32 GHz). MMIC modulators with drivers to provide large linear phase modulation (above 2.5 radians), high-data rate BPSK/QPSK modulation at X-band (8.4 GHz) and Ka-band. Miniature, ultra-stable and voltage-controlled oscillators for deep space communications and GPS applications. Miniature, low-loss X-band and Ka-band switches and diplexers.
- Advanced Ka-band MMIC and photonic packages for high data rate (1 Gbps) applications.
- Miniature, high-efficiency power amplifiers and RF power devices operating in the X- and Ka-band, transmitters with output power levels up to 20 watts that can survive the space environment with a minimum mean-time-to-failure of ten years.

Optical Communications
- Efficient (greater than 20 percent wall plug), lightweight (less than 1kg including drivers), flight-qualifiable, actively Q-switched laser transmitters (diode-pumped based) with 1 to 3 W of average output power at repetition rates between 5 and 50 kHz. Pulse generation time delay uncertainty should be less than 1 nsec with a pulse-width no greater than 30 ns. High (> 1000) modulation extinction ratio is highly desirable.
- Novel schemes for stray-light control and sunlight mitigation. Also, transmit/receive isolation methods providing at least 130 dB of isolation.
- Acquisition and tracking technologies including algorithms for sub-micro-radian laser beam pointing from deep-space ranges.
- Low power consumption, high quantum efficiency and fill factor and compact acquisition and tracking focal plane array detectors incorporating on-chip processing for window control, pixel gain/offset correction window, background/pattern noise calibration, bright spot location for initial acquisition, and pixel summation mode. Multiple windowing capability with different integration times for each window is also highly desirable.
- Lightweight high precision (< 0.1 micro-rad over 1-500 Hz) inertial reference sensors for use onboard spacecraft) inertial reference sensors (gyros,) for use onboard spacecraft.
- Silicon Avalanche Photodiode Detectors (APD) with > 3 mm active area diameter, bandwidth > 200 MHz, QE > 40 percent at 1064 nm, very low noise (k factor < 0.1) and gain > 100. Also, 250 micron diameter (Si APD) detector/amplifier with sufficient bandwidth for 2.5 Gbps communications.

S4.07 Deep Space Power and Propulsion Systems
Lead Center: GRC
Participating Center(s): JPL, JSC, MSFC

Innovative concepts utilizing advanced technology are solicited in the areas of energy conversion, storage, power electronics, and power system materials. Power levels of interest range from tens of milliwatts to several kilowatts. NASA Space Science missions require energy systems with high energy density, reliability and low overall costs (including operations). Likewise, propulsion is a critical technology area for Space Science missions. Propulsion functions include precision positioning, in-space maneuvering, vehicle reaction control, planetary injection, and planetary descent/ascent. The mass and volume of spacecraft are usually dominated by the propulsion system, limiting mission capabilities. Innovations are needed in chemical and electric propulsion technologies to reduce the mass and volume of propulsion systems while increasing their capability, reliability, and lifetime. Advances are sought in the following areas:

Energy Conversion
Advances in photovoltaic technology are sought, including rigid arrays, thin film arrays, and concentrator arrays with substantial increases in specific power (w/kg) and decreased cost. Must accommodate radiation resistance, low temperature/low intensity, and high temperature/ high intensity operation.

Advances in radioisotope power conversion to electricity (tens of milliwatts to hundreds of watts with efficiencies > 20 percent). Includes advances in AMTEC, thermophotovoltaics, thermoelectrics, Stirling, and microfabricated power systems.

Energy Storage
Includes advances in primary and secondary (rechargeable) battery technologies. Technologies include lithium ion batteries, lithium polymer batteries and other advanced concepts providing dramatic increases in mass and volume energy density (w-hr/kg and w-hr/liter). Must be able to operate in harsh environments, including high radiation and low/high temperature regimes.

For operation on planetary surfaces, the use of regenerative fuel cells, both conventional and unitized - passive designs, with substantial increases in mass and volume specific energy for those situations where there are substantial time periods of charging/recharge (anywhere from hours to days).

Power Electronics
Advanced electronic technologies with reduced volume and mass capable of high-temperature, low-temperature (cryogenic), or wide-temperature operation, radiation resistance, and/or electromagnetic shielding with thermal control.

Thermal control integral to electrical devices capable of > 100 W/cm2 heat flux.

Advanced electronic materials, devices and circuits including transformers, integrated circuits, capacitors, ultra capacitors, electro-optical devices, micro electro-mechanical systems (MEMS), sensors, low loss magnetic cores, motor drives, electrical actuation.

Advanced PMAD control technologies including fault detection, isolation, and system reconfiguration, including "smart components," built-in test, health management, and power-line or wireless communication.

Power System Materials
Advances are sought in materials, surfaces, and components that are durable for atomic oxygen, soft x-ray, electron, proton, and ultraviolet radiation and thermal cycling environments, lightweight electromagnetic interference shielding, and high-performance, environmentally durable radiators.

Propulsion Systems
Advanced electric propulsion technologies, including thrusters and advanced power processing, are needed for robotic planetary transportation applications. Technologies are sought that increase efficiency, reduce mass, and reduce system complexity. High-performance, bipropellant technologies (specific impulse > 350 sec) are of high

interest for planetary propulsion applications. Micropropulsion technologies, applicable to spacecraft that less than 40 kg, are of high interest to Space Science. These propulsion technologies should emphasize system simplicity, low power requirements, minimal mass, and leverage the unique nature of microscale devices. Propellant management components (valves, flow control/regulation, fluid isolation) are needed for all of the electric, chemical, and micro propulsion systems described above.

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8.2 STTR Research Topics

To reduce overlap and streamline administrative and programmatic functions, NASA has established areas of excellence for each of its field installations. The most significant, as noted in NASA's management plan, are termed Centers of Excellence (CE). There is one CE for each NASA installation. Each CE represents a focused, Agency-wide leadership responsibility in a specific area of technology or knowledge. CE's are charted with a clear definition of their capabilities and boundaries. They are chartered to be preeminent within the Agency, if not worldwide, with respect to the human resources, facilities, and other critical capabilities associated with the particular area of excellence. Each CE must maintain or increase the Agency's preeminent position in their assigned area in line with the program requirements of the Strategic Enterprises and the long-term interests of the Agency. The NASA STTR Program is aligned with the CE's. This year four CE's are participating. Research topics rotate each year among the different CE's. The topic will be focused on some of the product areas or challenges faced by the CE.

8.2.1 Human Operations in Space: Intelligent Medical Systems
NASA Installation: Johnson Space Center (JSC)

The Center of Excellence for Human Operations in Space seeks to expand the human experience into the far reaches of space through exploring, using, and enabling the development of space. Within these goals, the practice of medicine in space is confounded by severe restrictions on vehicle and personnel resources. Current medical operations concepts rely on non-physician astronauts with minimal medical experience who are supported by extensive communications with Earth-based medical personnel. As we move to longer duration missions further from Earth or involve more dangerous activities such as significant "hard hat" construction activities in space, the need for more autonomous emergency medical care becomes acute. A human Mars mission, for example, would take a multicultural crew of 4 to 6 people on a 6 to 8 month journey to the red planet. Upon arriving, the crew can expect to stay about 1.5 years on the surface before returning. Communication delays of up to 40 minutes round trip make emergency support from the ground an impossibility. Additionally, many medical emergencies normally require a team of doctors, nurses and other specialty medical professionals such as laboratory technicians, pharmacists, radiologists, and pathologists. Instead, a relatively small crew with specialties in electrical and mechanical engineering, astrobiology, geology, and other mission critical skills but little training and practice in emergency medical response will have to handle medical emergencies of all sorts under extremely stressful conditions. Clearly, intelligent medical systems will have to be devised to support these efforts and will have to become physician-equivalent helpers in the event of critical emergencies.

A variety of technologies are required including but not limited to:

- Visual programming shells/interfaces that allow physicians and other medical experts to easily capture their knowledge for diagnostic aids, decision support tools, medical protocol control, multimedia training tools, and other support systems.
- Methods of coordinating the activities of teams, such as control through RF linked palmtop computers or other means, to ensure adequate emergency medical response.
- Methods for rapidly entering medical records and comparison with existing records for rapid diagnostic support, allowing more natural and easier ways of interacting with or accessing medical knowledge in the context of real data.
- Medical data visualization techniques that provide large quantities of complex data in easy to understand and manipulate forms, allowing questions about the data to be easily and intuitively investigated in an interactive fashion.
- The use of physiological simulation models to aid in protocol and procedure development for emergency medical response.
- The use of detailed physiological models of individual patients in decision support to allow prediction of the effect of treatments or the administration of pharmaceuticals for guiding protocol selection in particular cases.
- On-the-spot tools for providing decision support and “just-in-time” training to allow relatively unskilled individuals to perform emergency treatment that they would not otherwise be capable of performing.
- Basic tools for creating intelligent, tutoring applications that can be used to insert medical training into long term missions, especially those that use a multimedia case study approach.
- Novel automated means for delivering various aspects of emergency medical care to free up crew members to take on other tasks.

8.2.2 Turbomachinery: Ultra-Efficient Engine Technology
NASA Installation: Glenn Research Center

The Center of Excellence for turbomachinery refers to turbine driven systems for propulsion, power generation, and energy conversion. These systems include rotating and related components and associated enabling technologies. Propulsion plays a critical role in enabling advanced aircraft designs and concepts required to achieve dramatic improvements in efficiencies of operations. Both overall cycle pressure ratio and turbine inlet temperature levels that can be achieved limit today's engine designs. Innovative, technological increases in both parameters are required to make improvements in performance and efficiency as well as minimizing global climate impact.

The ultra-efficient engine technology (UEET) program addresses local air quality concerns by developing technologies to reduce nitrogen oxide (NOx) emissions by 70 percent at landing and takeoff (LTO) conditions from the 1996 International Civil Aviation Organization (ICAO) standards. UEET also addresses potential ozone depletion concerns by providing combustor technologies that will not enable discernible aircraft impact on the ozone layer during cruise operation (up to a 90 percent reduction). Additionally, the UEET program addresses the potential of climate impact on long term aviation growth by providing critical propulsion technologies for a dramatic increase in efficiency to enable reductions of carbon dioxide (CO2) emissions based on an overall fuel savings goal of about 15 percent for large subsonic transport or as much as 8 percent for supersonic and/or small aircraft.

In general, UEET will require innovative technologies that will enable:

- Turbomachinery aerodynamic loading improvement (30 to 50 percent) relative to current best practices
- Increased turbine rotor inlet temperature capability (3100^{o} F) for performance with commercial engine life
- Engine weight reduction (20-25 percent) relative to current best practices
- Reduced cooling requirement (15 to 25 percent) relative to current best practices
- Cruise nitrogen oxide (NOx) production comparable to Landing/Takeoff NOx reduction
- Supersonic cruise nitrogen oxide (< 4 gm NOx/kg of fuel burned)

Innovations sought include:

- Propulsion Systems Integration and Assessment: Innovative tools that will enable rapid assessments of total conceptual systems and the systems' potential for meeting the Program goals. In addition, tools that can determine the levels of aerosols and particulates emitted from propulsion systems in order to determine health risk levels. Innovative tools that can aide the High Fidelity System Simulations that will be performed incorporating UEET technologies to better understand complex component interactions.
- Emissions Reduction: Innovative, low emissions, combustor concepts and technologies that will produce cleaner burning combustors to offset the increased NOx produced by the future, more fuel efficient engines with higher pressure ratios and temperatures. Novel combustion control approaches that will contribute to ultra-low levels of NOx production.
- Highly Loaded Turbomachinery: Revolutionary turbomachinery technologies for increased performance and efficiency that enable fuel burn (CO2 emissions) reductions of up to 15 percent. Inventive turbo-machinery technologies for lighter-weight, reduced-stage cores, low-pressure (LP) spools, and propulsors for high-performing, highly-efficient, and environmentally-compatible propulsion systems. Specifically, revolutionary concepts for significantly increased aero loading, trailing edge wake control, and higher cooling effectiveness. Innovative fan technologies that will reduce weight and increase efficiency while satisfying noise constraints.
- Revolutionary physics-based models for flow control, cooling, and particulate formation to understand the concepts and to design component hardware for rig test demonstrations of fan, core compressor, and HP/LP turbine systems.
- Materials and Structures for High Performance: Advanced high temperature materials that will enable high-performance, high efficiency, and environmentally compatible propulsion systems. Technologies for high temperature, highly durable, and lightweight materials and structures for engine systems.
- Propulsion-Airframe Integration (PAI): Development of advanced technologies to yield lower drag propulsion system integration with the airframe for a wide range of vehicle classes. Innovative tools that can aide the determination of optimum nacelle placement and optimum shaping to both the nacelle and the airframe to minimize drag. Inventive tools that can aide in active flow control.
- Intelligent Propulsion Controls: Revolutionary, autonomous, propulsion system designs which allow the control system, independent of pilot interaction, maximize performance across the particular mission profile while at the same time minimize environmental impact. Such a control system could also adjust system characteristics so as to maximize individual component life and, therefore, improve propulsion system life and safety.
- Technologies that include innovative, high temperature sensors that can measure gaseous emissions, exit gas temperatures, monitor combustion instabilities, as well as make noninvasive measurements of boundary layers to monitor separation.
- Inventive control logic to enable the minimization of combustor gaseous emissions, minimization of the combustion exit gas pattern factor, minimization of clearances between rotating and stationary hardware.

8.2.3 Materials and Structures: Materials Development

NASA Installation: Langley Research Center

This Center of Excellence for Materials and Structures targets innovative tools and revolutionary technologies for radically different materials and design concepts which can lead to significantly lower operating and manufacturing costs, increased flight safety, and markedly reduced structural weight in aerospace vehicles for the new millennium. A leap in traditional technologies currently available is necessary to enable revolutionary advances in aerospace materials development. The core technology challenge to support this Center of Excellence for this solicitation is:

Materials Development
Advanced synthetic materials are typically made by macroscale mixing of the required reactive components. This top down approach results in some control of parameters such as the distribution of molecular weights, microstructure and architecture of the product. However, the manufacture of advanced materials with mechanical properties and thermo-oxidative stability required for aerospace applications usually involves the use of hazardous chemicals for which waste disposal costs are high. In contrast, biological systems fabricate complex, multifunctional and robust materials, using a few basic components under non-hostile environmental conditions, to achieve structural control at the nanoscale (less than 100 nm) level. Biologically inspired methods for manufacture of high performance materials are sought. Areas of interest include the following:

- **Biomimetically Synthesized Materials**: Biological systems are capable of efficiently synthesizing materials for complex functions using very basic components. The secret is in the means by which hierarchical structural control is achieved. This mechanism for controlled fabrication at the nanoscale may be harnessed in revolutionary methods such as self-assembly to produce new materials suitable for aerospace use. Organic and metallic systems and fabrication processes that mimic biological structures and functions are sought. Some applications of interest are stimuli responsive materials for structural applications, adaptive optics, self-powered, structural components, functionally graded systems, controlled porosity, selective reinforcement and compositionally graded alloys.
- **Nanostructured Metal Systems**: The recent development of novel techniques has made possible the synthesis of a new class of materials with microstructure of characteristic dimension less than 100nm (nano-structure metals) and with potential for vastly improved performance. Work is needed to understand, at the smallest scale, the fundamental mechanisms controlling behavior of these new metal systems, and how the processing interacts with microstructure to determine engineering properties. Some emphasis should be placed on retention of property-optimized, nano-scale characteristics in bulk material and finished products.
- **Self-Repairing Systems**: Self-healing and self-repair are both characteristics desirable for materials useful in aerospace applications such as inflatable systems and structural components. Approaches to self-adaptive healing surfaces with the ability to sense, identify and repair damage are desirable. Various chemistries and/or design of mechanisms for self-repair in organic and metallic systems are sought.
- **Multifunctional Systems:** Multifunctionality may be achieved by the synergistic relationships in a multi-component system. Revolutionary methods for the fabrication of organic/inorganic hybrids capable of multiple functions including but not limited to self-healing, self-repairing, self-sensing, load bearing, and thermal protection are sought. These materials may be expected to perform in a hostile space environment, thus requiring atomic oxygen and radiation resistance as well as long-term durability under conditions that may include severe thermal cycling. Developments are needed for proof-of-concept demonstrations for unique, multifunction materials and structures for aerospace applications. Metal systems typically require surface modifications and/or treatment for protection in aggressive, high temperature, highly oxidative environments. Approaches are needed for tailored surface microstructures and coatings for environmental protection and thermal control on a variety of space transportation vehicles. Revolutionary approaches are needed for adaptive self-healing surfaces with the ability to sense, identify and repair damage.

8.2.4 Launch and Payload Processing Systems
NASA Installation: Kennedy Space Center

In support of the strategic development of NASA's Technology Plan, the Center of Excellence for Launch and Payload Processing Systems is continually advancing the state of the art in launch and payload processing hardware, software, and support activities. Development of innovative technologies needed to improve operational safety and reliability, reduce costs and shorten flight hardware processing turnaround times is critical to NASA's continued excellence in launch and payload processing. NASA's goals to achieve affordable access to space require greater efficiencies in ground operations for current and future space flight vehicles and payloads. The four primary goals of the Center of Excellence are to (1) assure that sound, safe, and efficient practices and processes are in place for privatized/commercialized launch site operations; (2) increase the use of KSC's operations expertise to contribute to the design and development of new payloads and launch vehicles; (3) utilize KSC's operations expertise in partnership with other entities (government, industry, academia) to develop new technologies for future space initiatives; and (4) continually embrace core capabilities (people, facilities, equipment, and systems) to meet agency objectives and customer needs for faster, better, and cheaper development and operations of space systems.
Core technology challenges to support this Center of Excellence for this Solicitation include:

Spaceport Range Technologies
Proposals should address the development of new concepts, methodologies, processes and technologies that may be applied to or are specific to Spaceport Range needs. Specific topic areas are:

- **Weather Instrumentation and Systems**: Research new and innovative sensors' instrumentation and system technologies that support the detection and real-time evaluation of atmospheric conditions that influence weather related decisions. These include remote sensing of atmospheric conditions; methods and algorithms for accurate predictions; multi-spectral instrumentation; and complex computational systems that affect the safety of launch and landing operations, and vehicle performance during these phases.
- **Spaceport Range Systems**: New and innovative technologies that include ground-based sensors and instrumentation that would safely reduce the required support infrastructure and personnel. Specific areas of need are metric tracking of vehicles, communications, navigational aids, detection of air and sea traffic, and weather sensors (see above). These sensors and instruments are intended to be complementary to the SBR (see below) and would be required to detect and monitor surface conditions by increasing the overall system resolution and accuracy and integrating the data.
- **Space Based Range (SBR)**: New and innovative in-space technologies that provide for simultaneous support of multiple vehicle operations at the same or other ranges/spaceports from space platforms. This will include the development of technologies for sensors and instrumentation systems that perform or support the following functions: metric tracking, area surveillance, navigation aids, and atmospheric sensing. Each of these functions will require development of one or more of the following technologies; Integrated multi-, hyper-, and ultra-spectral instrumentation and sensors; Multi-channel transceivers. These will provide directors/controllers and vehicles vital real-time data that is necessary to interface with the National Airspace System for all phases of ascent and decent.
- **Decision Models and Simulation**: New and innovative methods that safely reduce conservatism while providing the fidelity necessary to ensure safe and cost effective real-time decision models. Improvements in real-time computational capability and code development can significantly improve assessments. Specific technologies that would be necessary are:
  - Parallel processing enhancements associated with source term quantification will provide significant increases in performance.
  - Modeling code improvements will increase fidelity and improve understanding of potential problems.
  - Active model validation approach and simulators would be employed to ensure improvements have scientific merit and quantify model performance.
- **Range Information Systems Management**: New and innovative communications methods, standards and technologies that support the integration and management of geographically and functionally distributed instrumentation and computational systems into an integrated Spaceport(s) Range system.
- **Command, Control and Monitoring**: New and Innovative technologies that include real-time advisory systems for the operators and users; data reduction, analysis, and archiving; configuration validation and management; and low cost high fidelity training capabilities that minimize impact to operational systems.

Process Engineering
Proposals should address the development of new concepts, methodologies, processes, and/or software support systems that advance the state-of-the-art in process engineering technologies. Specific areas of emphasis include, but are not limited to, those topics listed below:

- **Systems, Process, and Operations Modeling, and Simulation and Analysis**: New technologies must be developed and existing technologies improved in the area of ground processing assessments for any future launch vehicles including both Expendable Launch Vehicle (ELV) and Reusable Launch System (RLS), development and assessment of Mars/moon surface operations, sparing analysis for human Mars/moon missions, discrete event simulation and modeling and analysis techniques, automated process simulation and processing systems and virtual shuttle processing models.
- **Human Factors (HF) Engineering**: Innovative research is needed in the area of assessments on the human Mars/moon vehicle design, application of HF principles early in the design stages of systems to prevent and reduce human error, perform usability testing on systems and prototypes, development of advanced intelligent training systems and wireless communication headsets.
- **Process Design and Development**: There is a need for advanced technologies to be developed in the area of optimization of new processes, knowledge capture systems, work instruction systems, and management support systems.
- **Work Methods/Measurement**: Research is needed in the advancement of tools to assist in the development and assessment of crew timelines for human Mars/moon missions and work methods and measurement techniques.
- **Scheduling/Capacity Analysis**: New technologies must be developed in the area of assessments of crew timelines for human Mars/moon missions from the perspective of expected maintenance demands versus allocated crew time to perform maintenance, advanced resource and schedule optimization systems, and smart storage and inventory systems.
- **Risk and System Assessment**: Innovative research must be developed in the area of identification of enhanced risk assessment techniques from a systems integration perspective, lessons learned database, application of safety hazard analysis, failure mode effects analysis (FMEA) and critical items list (CIL), fault tree analysis, reliability, maintainability and availability predictions (mean time between failures (MTBF), mean time to repair (MTTR), etc.). Additional enhancements needed in generating quantitative risk assessments such as Fault Tree Analyses linked to an Event Tree serving as a pivotal event timeline (provides the probability of loss of vehicle or crew and detail component failures, which lead to this undesirable event.).

Regenerative Environmental Technologies
Proposals are solicited for innovative and commercially viable technologies in environmental monitoring and management of bioregenerative life support systems. Of particular emphasis is the development of systems or sensors to monitor functionality of a bioregenerative system and critical technologies for effective operation of the managed environment of a plant growth chamber. Specific topic areas are:

- **Functionality Monitoring for Bioregenerative Life Support**
  - <u>Microbial</u>: Innovative technologies for monitoring microbial populations in prototype systems under development at Kennedy Space Center are needed for better understanding the microbial community structure and function. Techniques are sought for rapid (real-time) identification and monitoring of the microbial ecology within hydroponic and bioreactor systems. Quantification of population size, species richness, community composition, microdiversity, and microbial growth are of particular interest. Techniques for direct analysis of microbial diversity without culturing are also desired.
  - <u>Plant Health</u>: Novel techniques for automatic/remote detection of plant stresses are sought for use in plant growth chambers using lighting systems. Plants stresses to be identified include but are not limited to changes in atmospheric components and perturbations of hydroponic solutions such as nutrient deficiencies and toxicity's and microbial anomalies. Stress detection technique should preclude human intervention, i.e., robot and neural net recognition programming.
- **Technologies for Closed Plant Growth Systems**
  - <u>Lighting Systems</u>: Light sources which have a significant life cycle while also providing high electrical conversion efficiencies greater than 50 percent and producing an optimized radiation spectrum (e.g., 80 percent in 580-700nm and 20 percent in 400-480nm) for plant photosynthetic processes are highly sought. Innovative

methods for transferring/distributing light energy to the plant canopy (leaf surfaces) with minimal loss are also desired.

- Nutrient Monitoring: On-line and real-time monitoring of inorganic ions in plant nutrient solutions are desired. Simultaneous monitoring and quantification of nitrogen, phosphorous, potassium, calcium, chlorine, magnesium, sulfur, zinc, manganese, iron, boron, copper, and molybdenum are preferred.
- Atmospheric Monitoring: Real-time monitoring of the constituents of the chamber environment may be very helpful in identifying a negative trend in plant growth and allow corrective action if such parameters are found to be heading towards unfavorable limits. Desired measurements include but are no limited to: air temperature, air velocity, radiation, and the concentrations of the following atmospheric constituents: water, carbon dioxide, carbon monoxide nitrous oxide, gaseous nitrogen, oxygen, ammonia, ethylene, and argon. Low power, low mass, self-calibrating sensors as part of an overall sensor web are preferred.

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9. Submission Forms And Certifications

FORM 9A – SBIR PROPOSAL COVER

Subtopic Number

1. PROPOSAL NUMBER: **01-** _ _ . _ __ _ _ _ _
2. SUBTOPIC TITLE:
3. PROPOSAL TITLE:
4. SMALL BUSINESS CONCERN (SBC):
   NAME:
   MAILING ADDRESS:
   CITY/STATE/ZIP:
   PHONE:
   FAX:
   EIN/TAX ID: DUNS + 4: CAGE CODE:
   NUMBER OF EMPLOYEES:
5. AMOUNT REQUESTED $ _______________ DURATION: _________ MONTHS
6. CERTIFICATIONS: OFFEROR CERTIFIES THAT:

As defined in Section 1 of the Solicitation, the offeror certifies:		
a. Eligibility of the Principal Investigator	Yes	No
As defined in Section 2 of the Solicitation, the offeror qualifies as a:		
b. SBC	Yes	No
Number of employees: _____		
c. Socially and economically disadvantaged SBC	Yes	No
d. Woman-owned SBC	Yes	No
As described in Section 3 of this solicitation, the offeror meets the following requirements completely:		
e. All eleven parts of the technical proposal included in part order	Yes	No
f. Subcontracts/consultants proposed?	Yes	No
i) If yes, limits on subcontracts/consultants met	Yes	No
ii) If yes, copy of agreement enclosed	Yes	No
g. Government equipment or facilities required?	Yes	No
i) If yes, signed statement enclosed in Part 8	Yes	No

7. ACN NAME: E-MAIL:
8. ENDORSEMENTS:

PRINCIPAL INVESTIGATOR:	CORPORATE BUSINESS OFFICIAL:
NAME:	NAME:
TITLE:	TITLE:
PHONE:	PHONE:
E-MAIL:	E-MAIL:
SIGNATURE:	SIGNATURE:
DATE:	DATE:

NOTICE: For any purpose other than to evaluate the proposal, this data shall not be disclosed outside the Government and shall not be duplicated, used, or disclosed in whole or in part, provided that if a funding agreement is awarded to this proposer as a result of or in connection with the submission of these data, the Government shall have the right to duplicate, use, or disclose the data to the extent provided in the funding agreement. This restriction does not limit the Government's right to use Information contained in the data if it is obtained from another source without restriction. The data subject to this restriction are contained in pages __________ of this proposal

Guidelines for Completing SBIR Proposal Cover

1. Proposal Number: This number does not change even if the firm gets a new phone number. Complete the proposal number as follows:

   1. Enter the four-digit subtopic number.
   2. Enter the four digits system generated numbers

2. Subtopic Title: Enter the title of the subtopic that this proposal will address. Use abbreviations as needed.

3. Proposal Title: Enter a brief, descriptive title using no more than 80 keystrokes (characters and spaces). Do not use the subtopic title. Avoid words like "development" and "study".

4. Small Business Concern: Enter the full name of the company submitting the proposal. If a joint venture, list the company chosen to negotiate and receive contracts. If the name exceeds 40 keystrokes, please abbreviate.

Address:	Address where mail is received
City:	City name
State:	2-letter State designation (example VA for Virginia)
Zip:	9-digit Zip code (example 20705-3106)
Phone:	Number including area code
Fax:	Number including area code
EIN/Tax ID:	Employer Identification Number/Taxpayer ID
DUNS + 4:	9-digit Data Universal Number System plus a 4-digit suffix given by parent concern
CAGE Code:	Commercial Government and Entity Code (Issued by Central Contractor Registration (CCR))

5. Amount Requested: Proposal amount from Budget Summary. The amount requested should not exceed $70,000; round to nearest dollar; do not enter cents (see Sections 1.4.1, 5.1.1).

   Duration: Proposed duration in months. The requested duration should not exceed 6 months (see Sections 1.4.1, 5.1.1).

6. Certifications: Answer Yes or No as applicable for 6a, 6b, 6c, 6d and 6e (see Sections 1 and 2 for definitions)

   6f. Subcontracts/consultants proposed? By answering yes, the SBC certifies that subcontracts/consultants have been proposed and arrangements have been made to perform on the contract, if awarded.

   i) If yes, limits on subcontracting and consultants met: By answering yes, the SBC certifies that business arrangements with other entities or individuals do not exceed one-third of the work (amount requested including cost sharing if any, less fee, if any) and is in compliance with Section 3.2.4, Part 9

   ii) If yes, copy of agreement enclosed: By answering yes, the SBC certifies that a copy of any subcontracting or consulting agreements described in Section 3.2.4 Part 9 is included as required. Copy of the agreement may be submitted in a reduced size format.

   6g. Government furnished equipment required? By answering yes, the SBC certifies that unique, one-of-a-kind Government Furnished Facilities or Government Furnished Equipment are required to perform the proposed activities (see Sections 3.2.4 Part 8, 3.3 Part 7, 5.17). By answering no, the SBC certifies that no such Government Furnished Facilities or Government Furnished Equipment are required to perform the proposed activities.

   i) If yes, signed statement enclosed in Part 8: By answering yes, the SBC certifies that a statement describing the uniqueness of the facility and its availability to the offeror at specified times, signed by the appropriate Government official is enclosed in the proposal.

7. ACN Name and E-mail: Name and e-mail address of Authorized Contract Negotiator

8. Endorsements: The proposal cover must be signed by an official of the firm and proposed Principal Investigator

The Proposal Cover is submitted with original signatures in paper form to NASA with the proposal.

FORM 9B – SBIR PROPOSAL SUMMARY

Subtopic Number

1. PROPOSAL NUMBER **01- _ _ . _ __**

2. SUBTOPIC TITLE

3. PROPOSAL TITLE

4. SMALL BUSINESS CONCERN
   NAME:
   ADDRESS:
   CITY/STATE:
   ZIP:
   PHONE:

5. PRINCIPAL INVESTIGATOR/PROJECT MANAGER
   NAME:
   ADDRESS:
   CITY/STATE:
   ZIP:
   PHONE:

6. TECHNICAL ABSTRACT (LIMIT 200 WORDS):

7. POTENTIAL COMMERCIAL APPLICATIONS (LIMIT 200 WORDS):

Guidelines for Completing SBIR Proposal Summary

Complete Form 9B electronically and print a copy for second page of the proposal.

1. **Proposal Number:** Same as Proposal Cover.

2. **Subtopic Title:** Same as Proposal Cover.

3. **Proposal Title:** Same as Proposal Cover.

4. **Small Business Concern:** Same as Proposal Cover.

5. **Principal Investigator/Project Manager:** Same as Proposal Cover

6. **Technical Abstract:** Summary of the offeror's proposed project in 200 words or less. The abstract must not contain proprietary information and must describe the NASA need addressed by the proposed R/R&D effort.

7. **Potential Commercial Application(s):** Summary of the direct or indirect commercial potential of the project, assuming the goals of the proposed R/R&D are achieved. Limit your response to 200 words.

FORM 9C – SBIR SUMMARY BUDGET

PROPOSAL NUMBER:

SMALL BUSINESS CONCERN:

DIRECT LABOR:

Category	Hours	Rate	Cost	
			$	
			TOTAL DIRECT LABOR: (1)	$ ______________

OVERHEAD COST
______% of Total Direct Labor or $ ______

	OVERHEAD COST: (2)	$ ______________

OTHER DIRECT COSTS (ODCs):

Category	Cost	
	$	
	TOTAL OTHER DIRECT COSTS: (3)	$ ______________
(1)+(2)+(3)=(4)	SUBTOTAL: (4)	$ ______________
GENERAL & ADMINISTRATIVE (G&A) COSTS ______% of Subtotal or $ ______	G&A COSTS: (5)	$ ______________
(4)+(5)=(6)	TOTAL COSTS (6)	$ ______________
ADD PROFIT or SUBTRACT COST SHARING (As applicable)	PROFIT/COST SHARING: (7)	$ ______________
(6)+(7)=(8)	AMOUNT REQUESTED: (8)	$ ______________

Guidelines for Preparing SBIR Summary Budget

The offeror submits to the Government a pricing proposal of estimated costs with detailed information for each cost element, consistent with the offeror's cost accounting system. Prepare electronically, print and sign a paper copy for submission to NASA with the proposal.

This summary does not eliminate the need to fully document and justify the amounts requested in each category. Such documentation should be contained, as appropriate, on a budget explanation page immediately following the summary budget in the proposal.

Firm: Same as Proposal Cover.

Proposal Number: Same as Proposal Cover.

Direct Labor: Enter labor categories proposed (e.g., Principal Investigator/Project Manager, Research Assistant/laboratory assistant, Analyst, administrative staff), labor rates and the hours for each labor category.

Overhead Cost: Specify current rate and base. Use current rate(s) negotiated with the cognizant federal auditing agency, if available. If no rate(s) has (have) been negotiated, a reasonable indirect cost (overhead) rate(s) may be requested for Phase I for acceptance by NASA. Show how this rate is determined. The offeror may use whatever number and types of overhead rates that are in accordance with the firm's accounting system and approved by the cognizant federal negotiating agency, if available. Multiply Direct Labor Cost by the Overhead Rate to determine the Overhead Cost.

<u>Example</u>: A typical SBC might have an overhead rate of 30 percent. If the total direct labor costs proposed are $50,000, the computed overhead costs for this case would be .3x50,000=$15,000, if the base used is the total direct labor costs.

or provide a number for total estimated overhead costs to execute the project.

Other Direct Costs (ODCs):

- Materials and Supplies: Indicate types required and estimate costs.
- Documentation Costs or Page Charges: Estimate cost of preparing and publishing project results.
- Subcontracts: Include a completed budget including hours and rates and justify details. (Section 3.2.4, Part 9.)
- Consultant Services: Indicate name, daily compensation, and estimated days of service.
- Computer Services: Computer equipment leasing is included here.

List all other direct costs that are not otherwise included in the categories described above.

Subtotal (4): Sum of (1) Total Direct Labor, (2) Overhead and (3) ODCs

General and Administrative (G&A) Costs (5): Specify current rate and base. Use current rate negotiated with the cognizant federal negotiating agency, if available. If no rate has been negotiated, a reasonable indirect cost (G&A) rate may be requested for acceptance by NASA. Show how this rate is determined. If a current negotiated rate is not available, NASA will negotiate a reasonable rate with the offeror. Multiply (4) subtotal (Total Direct Cost) by the G&A rate to determine G&A Cost.

or provide an estimated G&A costs number for the proposal.

Total Costs (6): Sum of Items (4) and (5). Note that this value will be used in verifying the minimum required work percentage for the SBC.

Profit/Cost Sharing (7): See Sections 5.11 and 5.12. Profit to be added to total budget, shared costs to be subtracted from total budget, as applicable.

Amount Requested (8): Sum of Items (6) and (7), not to exceed $70,000.

SBIR CHECK LIST

For assistance in completing your proposal, use the following checklist to ensure your submission is complete.

1. The entire proposal including any supplemental material shall not exceed a total of 25 8.5 x 11 inch pages, (Section 3.2.1).

2. The proposal and innovation is submitted for one subtopic only. (Section 3.1).

3. The entire proposal is submitted consistent with the requirements and in the order outlined in Section 3.2

4. The technical proposal contains all eleven parts in order. (Section 3.2.4).

5. Certifications in Form 9A are completed.

6. Proposed funding does not exceed $70,000. (Sections 1.4.1, 5.1.1).

7. Proposed project duration should not exceed 6 months. (Sections 1.4.1, 5.1.1).

8. Printed version of Forms 9A, 9B and 9C included in the postal submission.

9. Postal submission includes an original signed proposal with all forms (Section 6.3).

10. Entire proposal including Forms 9A, 9B and 9C submitted via the Internet.

11. Internet submission must be consistent with Postal submission.

12. Proposals must be received by the NASA SBIR/STTR Program Support Office no later than 5:00 p.m. EDT on Wednesday, June 6, 2001. (Section 6.3.3).

FORM 9A – STTR PROPOSAL COVER

Topic Number

1. PROPOSAL NUMBER: **01-** _ _ . _ __

2. RESEARCH TOPIC:

3. PROPOSAL TITLE:

4. SMALL BUSINESS CONCERN (SBC)

SMALL BUSINESS CONCERN (SBC)	RESEARCH INSTITUTION (RI)
NAME:	NAME:
ADDRESS:	ADDRESS:
CITY/STATE/ZIP:	CITY/STATE/ZIP:
PHONE:	PHONE:
FAX:	FAX:
EIN/TAX ID:	EIN/TAX ID:
DUNS + 4: CAGE CODE:	

5. AMOUNT REQUESTED: $_____________________ DURATION: _________ MONTHS

6. <u>CERTIFICATIONS</u>: THE ABOVE SBC AND RI CERTIFY THAT

As defined in Section 2 of the Solicitation, the offeror qualifies as a:			
a.	SBC	Yes	No
	Number of employees: ____		
b.	RI	Yes	No
c.	Socially and economically disadvantaged SBC	Yes	No
d.	Woman-owned SBC	Yes	No
As described in Section 3 of this solicitation, the offeror meets the following requirements completely:			
e.	Cooperative Agreement signed by the SBC and RI enclosed	Yes	No
f.	All eleven parts of the technical proposal included in part order	Yes	No
g.	Subcontracts/consultants proposed?	Yes	No
	i) If yes, limits on subcontracts/consultants met	Yes	No
	ii) If yes, copy of agreement enclosed	Yes	No
h.	Government equipment or facilities required?	Yes	No
	i) If yes, signed statement enclosed in Part 8	Yes	No

7. ACN NAME: E-MAIL:

8. THE SBC WILL PERFORM ___% OF THE WORK AND THE RI WILL PERFORM ___% OF THE WORK OF THIS PROJECT.

9. ENDORSEMENTS:

SBC OFFICIAL:	PI/PM:	RI OFFICIAL:
NAME:	NAME:	NAME:
TITLE:	EMPLOYER:	TITLE:
PHONE:	PHONE:	PHONE:
E-MAIL:	E-MAIL:	E-MAIL:
SIGNATURE:	SIGNATURE:	SIGNATURE:
DATE:	DATE:	DATE:

NOTICE: For any purpose other than to evaluate the proposal, this data shall not be disclosed outside the government and shall not be duplicated, used, or disclosed in whole or in part, provided that, if a funding agreement is awarded to this proposer as a result of or in connection with the submission of these data, the Government shall have the right to duplicate, use, or disclose the data to the extent provided in the funding agreement. This restriction does not limit the Government's right to use information contained in the data if it is obtained from another source without restriction. The data subject to this restriction are contained in pages _____ of this proposal.

Guidelines for Completing STTR Proposal Cover

General: Complete Form 9A electronically by following the instructions provided in the electronic handbook. Print one copy of Form 9A and sign it manually. This will be the signed cover sheet for the paper copy of the proposal to be submitted to NASA along with the internet submission (see Sections 3.2, 6.2 for further instructions.)

1. Proposal Number: This number does not change even if the firm gets a new phone number. Complete the proposal number as follows:

    1. Enter the four-digit Topic number.
    2. Enter the four digits system generated numbers

2. Research Topic: NASA research topic number and title (Section 8).

3. Proposal Title: A brief, descriptive title, avoid words like "development of" and "study of" and do not use acronyms or trade names.

4. Small Business Concern: Full name and address of the company submitting the proposal. If a joint venture, list the company chosen to negotiate and receive contracts. If the name exceeds 40 keystrokes, please abbreviate.

    Research Institution: Full name and address of the research institute.

Mailing Address:	Address where mail is received
City:	City name
State:	2-letter State designation (example VA for Virginia)
Zip:	9-digit Zip code (example 20705-3106)
Phone:	Number including area code
Fax:	Number including area code
EIN/TAX ID:	Employer Identification Number/Taxpayer ID
DUNS + 4:	9-digit Data Universal Number System plus a 4-digit suffix given by parent concern
CAGE Code:	Commercial Government and Entity Code (Issued by Central Contractor Registration (CCR)

5. Amount Requested: Proposal amount from Budget Summary. The amount requested should not exceed $100,000; round to nearest dollar; do not enter cents (see Sections 1.4.1, 5.1.1).

    Duration: Proposed duration in months. The requested duration should not exceed 12 months (see Sections 1.4.1, 5.1.1).

6. Certifications: Answer Yes or No as applicable for 5a, 5b, 5c, and 5d (see Section 2 for definitions)

    5e. Cooperative Agreement signed by the SBC and RI: By answering yes, the SBC/RI certifies that a Cooperative Agreement signed by both SBC and RI is enclosed in the proposal (see Sections 3.2.2, 3.2.6).

    5f. All eleven parts of the technical proposal included: By answering yes, the SBC/RI certifies that the proposal consists of all eleven parts numbered and in the prescribed order (see Section 3.2.4).

    5g. Subcontracts/consultants proposed? By answering yes, the SBC/RI certifies that subcontracts/consultants have been proposed and arrangements have been made to perform on the contract, if awarded.

    i) If yes, limits on subcontracting and consultants met: By answering yes, the SBC/RI certifies that business arrangements with other entities or individuals do not exceed 30 percent of the work (amount requested including cost sharing if any, less fee, if any) and is in compliance with Section 3.2.4, Part 9

ii) If yes, copy of agreement enclosed: By answering yes, the SBC/RI certifies that a copy of any subcontracting or consulting agreements described in Section 3.2.4 Part 9 is included as required. Copy of the agreement may be submitted in a reduced size format.

5h. Government furnished equipment required? By answering yes, the SBC/RI certifies that unique, one-of-a-kind Government Furnished Facilities or Government Furnished Equipment are required to perform the proposed activities (see Sections 3.2.4 Part 8, 3.3 Part 7, 5.17). By answering no, the SBC/RI certifies that no such Government Furnished Facilities or Government Furnished Equipment are required to perform the proposed activities.

i) If yes, signed statement enclosed in Part 8: By answering yes, the SBC/RI certifies that a statement describing the uniqueness of the facility and its availability to the offeror at specified times, signed by the appropriate Government official is enclosed in the proposal.

7. ACN Name and E-mail: Name and e-mail address of Authorized Contract Negotiator.

8. Proposals submitted in response to this Solicitation must be jointly developed by the SBC and the RI, and at least **40 percent** of the work (amount requested including cost sharing, less fee, if any) is to be performed by the SBC as the prime contractor, and at least **30 percent** of the work is to be performed by the RI (see Section 1.1).

9. Endorsements: The proposal cover must be signed by an official of the firm, proposed Principal Investigator/Project Manager and the RI Official.

The Proposal Cover is submitted with original signatures in paper form to NASA with the proposal.

FORM 9B – STTR PROPOSAL SUMMARY

Topic Number

1. PROPOSAL NUMBER **01- __ __ . __ __.**

2. RESEARCH TOPIC:

3. PROPOSAL TITLE:

4. SMALL BUSINESS CONCERN
   NAME:
   ADDRESS:
   CITY/STATE:
   ZIP:
   PHONE:

5. RESEARCH INSTITUTION
   NAME:
   ADDRESS:
   CITY/STATE:
   ZIP:
   PHONE:

6. PRINCIPAL INVESTIGATOR/PROJECT MANAGER:

7. TECHNICAL ABSTRACT (LIMIT 200 WORDS):

8. POTENTIAL COMMERCIAL APPLICATION(S) (LIMIT 200 WORDS):

Guidelines for Completing STTR Proposal Summary

Complete Form 9B electronically and print a copy for second page of the proposal.

1. **Proposal Number:** Same as Proposal Cover

2. **Research Topic:** Same as Proposal Cover.

3. **Proposal Title:** Same as Proposal Cover.

4. **Small Business Concern:** Same as Proposal Cover.

5. **Research Institution:** Same as Proposal Cover.

6. **Principal Investigator/Project Manager:** Same as Proposal Cover.

7. **Technical Abstract:** Summary of the offeror's proposed project in 200 words or less. The abstract must not contain proprietary information and must describe the NASA need addressed by the proposed R/R&D effort.

8. **Potential Commercial Application(s):** Summary of the direct or indirect commercial potential of the project, assuming the goals of the proposed R/R&D are achieved. Limit your response to 200 words.

FORM 9C – STTR SUMMARY BUDGET

PROPOSAL NUMBER:

SMALL BUSINESS CONCERN: PRINCIPAL INVESTIGATOR/PROJECT MANAGER:

DIRECT LABOR:

Category	Hours	Rate	Cost	
			$	
			TOTAL DIRECT LABOR: (1)	$ ______________

OVERHEAD COST
______% of Total Direct Labor or $ ______

OVERHEAD COST: (2)	$ ______________

OTHER DIRECT COSTS (ODCs):

Category	Cost	
	$	
	TOTAL OTHER DIRECT COSTS: (3)	$ ______________
(1)+(2)+(3)=(4)	SUBTOTAL: (4)	$ ______________
GENERAL & ADMINISTRATIVE (G&A) COSTS ______% of Subtotal or $ ______	G&A COSTS: (5)	$ ______________
(4)+(5)=(6)	TOTAL COSTS (6)	$ ______________
ADD PROFIT or SUBTRACT COST SHARING (As applicable)	PROFIT/COST SHARING: (7)	$ ______________
(6)+(7)=(8)	AMOUNT REQUESTED: (8)	$ ______________

Guidelines for Preparing STTR Summary Budget

The offeror submits to the Government a pricing proposal of estimated costs with detailed information for each cost element, consistent with the offeror's cost accounting system. Prepare electronically, print and sign a paper copy for submission to NASA with the proposal.

This summary does not eliminate the need to fully document and justify the amounts requested in each category. Such documentation should be contained, as appropriate, on a budget explanation page immediately following the summary budget in the proposal.

Small Business Concern - Same as Proposal Cover.

Principal Investigator/Project Manager - Same as Proposal Cover.

Direct Labor - Enter labor categories proposed (e.g., Principal Investigator/Project Manager, Research Assistant/laboratory assistant, Analyst, administrative staff), labor rates and the hours for each labor category.

Overhead Cost - Specify current rate and base. Use current rate(s) negotiated with the cognizant federal auditing agency, if available. If no rate(s) has (have) been audited, a reasonable indirect cost (overhead) rate(s) may be requested for Phase I for acceptance by NASA. Show how this rate is determined. The offeror may use whatever number and types of overhead rates that are in accordance with the firm's accounting system and approved by the cognizant federal negotiating agency, if available. Multiply Direct Labor Cost by the Overhead Rate to determine the Overhead Cost.

<u>Example</u>: A typical SBC might have an overhead rate of 30%. If the total direct labor costs proposed are $50,000, the computed overhead costs for this case would be .3x50,000=$15,000, if the base used is the total direct labor costs.

or **provide a number for total estimated overhead costs to execute the project.**

Other Direct Costs (ODCs) - (Include budget for the Research Institution as a Other Direct Cost.)

- Materials and Supplies: Indicate types required and estimate costs.
- Documentation Costs or Page Charges: Estimate cost of preparing and publishing project results.
- Subcontracts: Include a completed budget including hours and rates and justify details. (Section 3.2.4, Part 9.)
- Consultant Services: Indicate name, daily compensation, and estimated days of service.
- Computer Services: Computer equipment leasing is included here.

List all other direct costs that are not otherwise included in the categories described above.

Subtotal (4) - Sum of (1) Total Direct Labor, (2) Overhead and (3) ODCs

General and Administrative (G&A) Costs (5)- Specify current rate and base. Use current rate negotiated with the cognizant federal negotiating agency, if available. If no rate has been negotiated, a reasonable indirect cost (G&A) rate may be requested for acceptance by NASA. If a current negotiated rate is not available, NASA will negotiate a reasonable rate with the offeror. Multiply (4) subtotal (Total Direct Cost) by the G&A rate to determine G&A Cost.

or provide an estimated G&A costs number for the proposal.

Total Costs (6) - Sum of Items (4) and (5). Note that this value will be used in verifying the minimum required work percentage for the SBC and RI.

Profit/Cost Sharing (7) - See Sections 5.11 and 5.12. Profit to be added to total budget, shared costs to be subtracted from total budget, as applicable.

Amount Requested (8) - Sum of Items (6) and (7), not to exceed $100,000.

Name and Title of SBC Official:

Signature and Date

MODEL COOPERATIVE AGREEMENT

By virtue of the signatures of our authorized representatives, _________(Small Business Concern), and _______________________________(Research Institution)_________________________ have agreed to cooperate on the _________(Proposal Title)_________ Project, in accordance with the proposal being submitted with this agreement.

This agreement shall be binding until the completion of all Phase I activities, at a minimum. If the________ ________(Proposal Title)_________ Project is selected to continue into Phase II, the agreement may also be binding in Phase II activities that are funded by NASA, then this agreement shall be binding until those activities are completed. The agreement may also be binding in Phase III activities that are funded by NASA.

After notification of Phase I selection and prior to contract release, we shall prepare and submit, if requested by NASA, an **Allocation of Rights Agreement**, which shall state our rights to the intellectual property and technology to be developed and commercialized by the _________________(Proposal Title)_________ Project. We understand that our contract cannot be approved and project activities may not commence until the **Allocation of Rights Agreement** has been signed and certified to NASA.

Please direct all questions and comments to _______________(Small Business Concern representative) at ________(Phone Number)_______________

________Signature______________________

________Name/title_____________________

________Small Business Concern_________

________Signature______________________

________Name/title_____________________

________Research Institution_____________

SMALL BUSINESS TECHNOLOGY TRANSFER (STTR) PROGRAM
MODEL ALLOCATION OF RIGHTS AGREEMENT

This Agreement between ____, a small business concern organized as a _________________________ under the laws of _________________ and having a principal place of business at ____
____________________, ("SBC") and ____, a research institution having a principal place of business at __________________________ _________________,("RI") is entered into for the purpose of allocating between the parties certain rights relating to an STTR project to be carried out by SBC and RI (hereinafter referred to as the "PARTIES") under an STTR funding agreement that may be awarded by _NASA________ to SBC to fund a proposal entitled "___________________________________ ____" submitted, or to be submitted, to by SBC on or about __________________________, 200___.

1. Applicability of this Agreement.

(a) This Agreement shall be applicable only to matters relating to the STTR project referred to in the preamble above.

(b) If a funding agreement for STTR project is awarded to SBC based upon the STTR proposal referred to in the preamble above, SBC will promptly provide a copy of such funding agreement to RI, and SBC will make a sub-award to RI in accordance with the funding agreement, the proposal, and this Agreement. If the terms of such funding agreement appear to be inconsistent with the provisions of this Agreement, the Parties will attempt in good faith to resolve any such inconsistencies.

However, if such resolution is not achieved within a reasonable period, SBC shall not be obligated to award nor RI to accept the sub-award. If a sub-award is made by SBC and accepted by RI, this Agreement shall not be applicable to contradict the terms of such sub-award or of the funding agreement awarded by NASA to SBC except on the grounds of fraud, misrepresentation, or mistake, but shall be considered to resolve ambiguities in the terms of the sub-award.

(c) The provisions of this Agreement shall apply to any and all consultants, subcontractors, independent contractors, or other individuals employed by SBC or RI for the purposes of this STTR project.

2. Background Intellectual Property.

(a) "Background Intellectual Property" means property and the legal right therein of either or both parties developed before or independent of this Agreement including inventions, patent applications, patents, copyrights, trademarks, mask works, trade secrets and any information embodying proprietary data such as technical data and computer software.

(b) This Agreement shall not be construed as implying that either party hereto shall have the right to use Background Intellectual Property of the other in connection with this STTR project except as otherwise provided hereunder.

(1) The following Background Intellectual Property of SBC may be used nonexclusively and, except as noted, without compensation by RI in connection with research or development activities for this STTR project (if "none" so state):____
____;

(2) The following Background Intellectual Property of RI may be used nonexclusively and, except as noted, without compensation by SBC in connection with research or development activities for this STTR project (if "none" so state):
____
____;

(3) The following Background Intellectual Property of RI may be used by SBC nonexclusively in connection with commercialization of the results of this STTR project, to the extent that such use is reasonably necessary for practical, efficient and competitive commercialization of such results but not for commercialization independent of the commercialization of such results, subject to any rights of the Government therein and upon the condition that SBC pay to RI, in addition to any other royalty including any royalty specified in the following list, a royalty of _____% of net sales or leases made by or under the authority of SBC of any product or service that embodies, or the manufacture or normal use of which entails the use of, all or any part of such Background Intellectual Property (if "none" so state):
____
_____________________________________.

3. Project Intellectual Property.

(a) "Project Intellectual Property" means the legal rights relating to inventions (including Subject Inventions as defined in 37 CFR § 401), patent applications, patents, copyrights, trademarks, mask works, trade secrets and any other legally protectable information, including computer software, first made or generated during the performance of this STTR Agreement.

(b) Except as otherwise provided herein, ownership of Project Intellectual Property shall vest in the party whose personnel conceived the subject matter, and such party may perfect legal protection in its own name and at its own expense. Jointly made or generated Project Intellectual Property shall be jointly owned by the Parties unless otherwise agreed in writing. The SBC shall have the first option to perfect the rights in jointly made or generated Project Intellectual Property unless otherwise agreed in writing.

(1) The rights to any revenues and profits, resulting from any product, process, or other innovation or invention based on the cooperative shall be allocated between the SBC and the RI as follows:

SBC Percent: ________ RI Percent: ________

(2) Expenses and other liabilities associated with the development and marketing of any product, process, or other innovation or invention shall be allocated as follows: the SBC will be responsible for ______ percent and the RI will be responsible for ______ percent.

(c) The Parties agree to disclose to each other, in writing, each and every Subject Invention, which may be patentable or otherwise protectable under the United States patent laws in Title 35, United States Code. The Parties acknowledge that they will disclose Subject Inventions to each other and the Agency within two months after their respective inventor(s) first disclose the invention in writing to the person(s) responsible for patent matters of the disclosing Party. All written disclosures of such inventions shall contain sufficient detail of the invention, identification of any statutory bars, and shall be marked confidential, in accordance with 35 U.S.C. § 205.

(d) Each party hereto may use Project Intellectual Property of the other nonexclusively and without compensation in connection with research or development activities for this STTR project, including inclusion in STTR project reports to the AGENCY and proposals to the AGENCY for continued funding of this STTR project through additional phases.

(e) In addition to the Government's rights under the Patent Rights clause of 37 CFR § 401.14, the Parties agree that the Government shall have an irrevocable, royalty free, nonexclusive license for any governmental purpose in any Project Intellectual Property.

(f) SBC will have an option to commercialize the Project Intellectual Property of RI, subject to any rights of the Government therein, as follows—

(1) Where Project Intellectual Property of RI is a potentially patentable invention, SBC will have an exclusive option for a license to such invention, for an initial option period of _______ months after such invention has been reported to SBC. SBC may, at its election and subject to the patent expense reimbursement provisions of this section, extend such option for an additional _______ months by giving written notice of such election to RI prior to the expiration of the initial option period. During the period of such option following notice by SBC of election to extend, RI will pursue and maintain any patent protection for the invention requested in

writing by SBC and, except with the written consent of SBC or upon the failure of SBC to reimburse patenting expenses as required under this section, will not voluntarily discontinue the pursuit and maintenance of any United States patent protection for the invention initiated by RI or of any patent protection requested by SBC. For any invention for which SBC gives notice of its election to extend the option, SBC will, within ______ days after invoice, reimburse RI for the expenses incurred by RI prior to expiration or termination of the option period in pursuing and maintaining (i) any United States patent protection initiated by RI and (ii) any patent protection requested by SBC. SBC may terminate such option at will by giving written notice to RI, in which case further accrual of reimbursable patenting expenses hereunder, other than prior commitments not practically revocable, will cease upon RI's receipt of such notice. At any time prior to the expiration or termination of an option, SBC may exercise such option by giving written notice to RI, whereupon the parties will promptly and in good faith enter into negotiations for a license under RI's patent rights in the invention for SBC to make, use and/or sell products and/or services that embody, or the development, manufacture and/or use of which involves employment of, the invention. The terms of such license will include: (i) payment of reasonable royalties to RI on sales of products or services which embody, or the development, manufacture or use of which involves employment of, the invention; (ii) reimbursement by SBC of expenses incurred by RI in seeking and maintaining patent protection for the invention in countries covered by the license (which reimbursement, as well as any such patent expenses incurred directly by SBC with RI's authorization, insofar as deriving from RI's interest in such invention, may be offset in full against up to _______ of accrued royalties in excess of any minimum royalties due RI); and, in the case of an exclusive license, (iii) reasonable commercialization milestones and/or minimum royalties.

(2) Where Project Intellectual Property of RI is other than a potentially patentable invention, SBC will have an exclusive option for a license, for an option period extending until ______ months following completion of RI's performance of that phase of this STTR project in which such Project Intellectual Property of RI was developed by RI. SBC may exercise such option by giving written notice to RI, whereupon the parties will promptly and in good faith enter into negotiations for a license under RI's interest in the subject matter for SBC to make, use and/or sell products or services which embody, or the development, manufacture and/or use of which involve employment of, such Project Intellectual Property of RI. The terms of such license will include: (i) payment of reasonable royalties to RI on sales of products or services that embody, or the development, manufacture or use of which involves employment of, the Project Intellectual Property of RI and, in the case of an exclusive license, (ii) reasonable commercialization milestones and/or minimum royalties.

(3) Where more than one royalty might otherwise be due in respect of any unit of product or service under a license pursuant to this Agreement, the parties shall in good faith negotiate to ameliorate any effect thereof that would threaten the commercial viability of the affected products or services by providing in such license(s) for a reasonable discount or cap on total royalties due in respect of any such unit.

4. Follow-on Research or Development.

All follow-on work, including any licenses, contracts, subcontracts, sub- licenses or arrangements of any type, shall contain appropriate provisions to implement the Project Intellectual Property rights provisions of this agreement and insure that the Parties and the Government obtain and retain such rights granted herein in all future resulting research, development, or commercialization work.

5. Confidentiality/Publication.

(a) Background Intellectual Property and Project Intellectual Property of a party, as well as other proprietary or confidential information of a party, disclosed by that party to the other in connection with this STTR project shall be received and held in confidence by the receiving party and, except with the consent of the disclosing party or as permitted under this Agreement, neither used by the receiving party nor disclosed by the receiving party to others, provided that the receiving party has notice that such information is regarded by the disclosing party as proprietary or confidential. However, these confidentiality obligations shall not apply to use or disclosure by the receiving party after such information is or becomes known to the public without breach of this provision or is or becomes known to the receiving party from a source reasonably believed to be independent of the disclosing party or is developed by or for the receiving party independently of its disclosure by the disclosing party.

(b) Subject to the terms of paragraph (a) above, either party may publish its results from this STTR project. However, the publishing party will give a right of refusal to the other party with respect to a proposed publication, as well as a _____ day period in which to review proposed publications and submit comments, which will be given full consideration before publication. Furthermore, upon request of the reviewing party, publication will be deferred for up to ______ additional days for preparation and filing of a patent application which the reviewing party has the right to file or to have filed at its request by the publishing party.

6. Liability.

(a) Each party disclaims all warranties running to the other or through the other to third parties, whether express or implied, including without limitation warranties of merchantability, fitness for a particular purpose, and freedom from infringement, as to any information, result, design, prototype, product or process deriving directly or indirectly and in whole or part from such party in connection with this STTR project.

(b) SBC will indemnify and hold harmless RI with regard to any claims arising in connection with commercialization of the results of this STTR project by or under the authority of SBC. The PARTIES will indemnify and hold harmless the Government with regard to any claims arising in connection with commercialization of the results of this STTR project.

7. Termination.

(a) This agreement may be terminated by either Party upon days written notice to the other Party. This agreement may also be terminated by either Party in the event of the failure of the other Party to comply with the terms of this agreement.

(b) In the event of termination by either Party, each Party shall be responsible for its share of the costs incurred through the effective date of termination, as well as its share of the costs incurred after the effective date of termination, and which are related to the termination. The confidentiality, use, and/or non-disclosure obligations of this agreement shall survive any termination of this agreement.

AGREED TO AND ACCEPTED--

Small Business Concern

By:____________________________________ Date:_____________
Print Name:____
Title:____

Research Institution

By:____________________________________ Date:_____________
Print Name:____
Title:____

STTR CHECK LIST

For assistance in completing your proposal, use the following checklist to ensure your submission is complete.

1. The entire proposal including any supplemental material shall not exceed a total of 25 8.5 x 11 inch pages, including Cooperative Agreement. (Sections 3.2.2, 3.2.6).

2. The proposal and innovation is submitted for one topic only. (Sections 1.4.1, 5.1.1).

3. The entire proposal is submitted consistent with the requirements and in the order outlined in Section 3.2

4. The technical proposal contains all eleven parts in order. (Section 3.2.4).

5. Certifications in Form 9A are completed.

6. Proposed funding does not exceed $100,000. (Sections 1.4.1, 5.1.1).

7. Proposed project duration should not exceed 12 months. (Sections 1.4.1, 5.1.1).

8. Cooperative Agreement is signed and included. (Sections 3.2.2, 3.2.6).

9. Printed version of Forms 9A, 9B and 9C included in the postal submission.

10. Postal submission includes an original signed proposal with all forms (Section 6.3).

11. Entire proposal including Forms 9A, 9B and 9C submitted via the Internet.

12. Internet submission must be consistent with Postal submission.

13. Proposals must be received by the NASA SBIR/STTR Program Support Office no later than by 5:00 p.m. EDT on Wednesday, June 6, 2001. (Section 6.3.3).

Appendix A: Phase I Sample Table of Contents

A sample table of contents to fulfill the part order requirements for the Technical Proposal (Section 3.2.4) is provided below:

Table of Contents

Part 1:	Table of Contents	Page 3
Part 2:	Identification and Significance of the Innovation	TBD
Part 3:	Technical Objectives	TBD
Part 4:	Work Plan	TBD
Part 5:	Related R/R&D	TBD
Part 6:	Key Personnel and Bibliography of Directly Related Work	TBD
Part 7:	Relationship with Phase II or Future R/R&D	TBD
Part 8:	Company Information and Facilities	TBD
Part 9:	Subcontracts and Consultants	TBD
Part 10:	Commercial Applications Potential	TBD
Part 11:	Similar Proposals and Awards	TBD

STTR: Each STTR proposal must also contain a Cooperative R/R&D Agreement between the SBC and RI, which is included as part of the 25-page limit.

Appendix B: Sample Format for Briefing Chart

NASA SBIR/STTR Technologies

Title of Proposal

PI: PI's Name / Firm – City, ST
Proposal No.: 01-I

Description and Objectives

<Place Picture Here>

Approach

Schedule and Deliverables

Subcontractors/Partners

NASA & Commercial Applications